

EFFECTS OF SHIFTING CULTIVATION
ON NATURAL SOIL CONSTITUENTS
IN CENTRAL AMERICA

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

January, 1960

ACKNOWLEDGMENTS

Sincere appreciation is extended to Dr. L. C. Hammond, Chairman of the writer's Supervisory Committee, for his patient guidance and supervision; to Dr. F. B. Smith, Head of the Soils Department, without whose interest field work outside the State of Florida would have been difficult; to members of his Supervisory Committee for their part in planning and supervising the research and course work; to Dr. A. E. Brandt for help in statistical interpretations of the data; and to Dr. H. C. Conklin, of Columbia University, for clarifying the anthropological picture.

The writer is also indebted to many residents of Guatemala who provided facilities and encouragement, especially to Messrs. Christopher and Alan Hempstead, whose farms were headquarters for most of the field work, and who provided very active assistance during the entire investigation; to Mr. Denis Koester who was generous with the facilities at Finca Seamay; and to Mr. Alan Probert who provided an early stimulus to the writer and reintroduced him to the Polochic Valley.

Gratitude is also expressed to the personnel of the Rockefeller Foundation who arranged financial assistance which made the field part of this investigation possible.

Through this study the writer first met many worthy friends.

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INTRODUCTION

Vast land areas of the humid tropics are used for shifting cultivation. Crops are planted and harvested in clearings that are cut and burned from the forest. After productivity declines, the land is abandoned to second growth and another forested site is cleared. Throughout the world there is increasing interest in replacing shifting cultivation with a more permanent type of agriculture. A growing world population, which is gradually outstripping its food supply, needs increasing agricultural production on lands now utilized for very short periods of time.

Large-scale research concerning this type of land use has not been sufficiently emphasized. Kellogg (1956) has stated the research needs thusly: "No research is more badly needed than that to establish the precise actions of the bush fallow. . . . I should rather know the answer to this question than that of any other unanswered question in soil science. The results affect millions of acres and millions of people." Meggers (1954) stressed the important influence of food resources on human culture by stating that, "The level to which a culture can develop is dependent upon the agricultural potentiality of the environment it occupies." The Food and Agriculture Organization of the United Nations (1957) estimated that the problem affected some 200 million people occupying 14 million square miles (34 million sq. km.), and Dobby (1950) reported that

approximately one-third of the total land area used for agricultural purposes in Southeast Asia was under shifting cultivation.

Researchers have previously examined the factors limiting the duration of time which land can be cropped under a system of shifting cultivation. Because these studies have yielded conflicting results, an investigation to determine the basic soil properties and how they change during the cycle--forest, crop, second growth--was undertaken on mountain slopes bordering the Polochic Valley in Guatemala, Central America. Since conditions restricting permanent crop production may vary geographically, fundamental knowledge of the soil changes which occur under shifting cultivation may be useful to predict more efficient and productive management practices after local limiting factors are recognized.

Soil samples from thirty fields under different stages of shifting cultivation were collected from eight sites within an area of approximately 100 square miles in the Polochic Valley. Locations were selected to include a range of ecological conditions so that the results might have wide application. Soil properties analyzed in the laboratory were: clay minerals, nitrogen, organic matter, cation exchange capacity, exchangeable bases (calcium, magnesium, potassium, and sodium), bulk density and extractible phosphorus, aluminum, manganese and zinc. Nitrification rates, micro-organisms and nematodes were examined in soils from four fields within the same area. In addition, extensive field data were collected on ecological factors.

The results of these analyses and their implications within the tropical rain forest environment are discussed in this presentation.

REVIEW OF LITERATURE

General Description of Shifting Cultivation

Throughout the humid tropics shifting cultivation follows the same basic pattern of forest, cleared land, and second growth. Local variations in shifting cultivation are usually limited to the types of crops and differences in the period of forest fallow. This changes slightly from place to place depending on the climate, soils and nature of second-growth vegetation. Detailed descriptions of this widespread practice were given by Conklin (1957), Cook (1921), De Schlippe (1956), FAO (1957), and Steggerda (1941).

The term "shifting cultivation" has not been universally accepted, but its use is more widespread than other names like the following: "fire agriculture" (Smith, 1954), "bush-fallowing rotation" (Barrau, 1958), "field-forest rotation" (Pelzer, 1945), "nomadic agriculture" (Tondeur and Bergeroo-Campragne, 1956), "swidden agriculture" (Conklin, 1957), "milpa agriculture" (Cook, 1921), "kaingin" (Pendleton, 1956), "chena" (Willis, 1922), and "ladang" (Gourou, 1956). "Shifting Cultivation" was the title for a symposium at the Ninth Pacific Science Congress, held in Bangkok, Thailand, November 18 to December 9, 1957. The Food and Agriculture Organization of the United Nations has frequently used this term in preference to others.

Shifting cultivation in Central America has been described by several authors. Cook (1921), Emerson (1953), Hester (1954),

Morley (1956), Steggerda (1941), and Thompson (1930) discussed the role of agriculture within the Maya Empire and compared it with present-day crop production in the same area. Morley pointed out that shifting cultivation nowadays in Mexico and Guatemala is identical to the type used for the past three thousand years in the area. The only recent innovation is the advent of steel tools--the axe and machete--which replaced the stone axes used formerly. The basic steps in preparing a field and growing a crop are almost universal wherever shifting cultivation is found.

The size of plots cleared for shifting cultivation each year vary in different areas. Villa (1945) obtained data on field size from fifty-two informants. He found that the average size of a field the first year after clearing the forest was 5.68 acres, of a second year field after forest was 3.67 acres, and a clearing after 7 or 8 years of second growth was 5.15 acres. Most of the informants made more than one clearing in a season. Steggerda (1941) found that the average field in Yucatan varied in size depending on the fertility of the soil. The average size of 638 fields based on five annual surveys was 9.8 acres.

Though shifting cultivation clearings are usually less than ten acres in size, the farmer needs much more land since, by necessity, part of it is in second growth each year and other areas are unusable. Cook (1921) calculated that 100 to 200 acres were needed per family in eastern Guatemala. In areas of less fertile soils this value might rise to 500 or 1,000 acres. Hester (1954), working in southern Mexico,

estimated that eleven acres would support one individual under bush fallowing; thus 59 persons could be supported per square mile.

Villa (1954) described several ecological observations which were used by the cultivator of Quintana Roo, Mexico in his selection of a desirable area for clearing: "He knows that black land (ek-luum) is more fertile than reddish land (kan-luum), that even better are the black lands on which grow wine palms or similar trees, called labcah because they are supposed to be the sites of ancient villages."

Occasionally one finds other reasons given for shifting cultivation instead of the environmental factors cited in the following pages. Holdridge (1947) described a case where social influences were involved:

The Haitian peasant's system of shifting cultivation is not entirely of his own making. . . . When questioned as to why they do not plant coffee or other permanent crops, they reply simply that if they worked hard to develop a valuable plot it would very likely be taken away from them by someone of more importance to the government.

Environmental Factors in Shifting Cultivation

Since shifting cultivation is a widespread problem of tropical regions many writers have delved into the possible limitations of continuous agriculture within the same areas. Many conflicting theories are found in a review of the literature. The possibility arises that limiting factors are not the same in all environments where shifting cultivation is practiced.

Vegetation

In humid tropical areas the growth and density of invading plant material far surpasses that facing farmers of temperate regions. Thus, the problem can be appraised more realistically by emphasizing vegetational succession rather than invasion by individual plants. The problem of grass invasion in the Polochic Valley will be discussed later. It has also been singled out as an important detriment in other areas of the tropics. Indeed, in Asia, lalang or cogon grass (Imperata cylindrica) has long been recognized as the most serious threat to a permanent system of agriculture (Pelzer, 1945; Pendleton, 1956).

Many workers have considered that the most important value of second growth forest is to eliminate herbaceous weeds rather than to restore soil properties. After a survey of northern Yucatán, Emerson (1953) concluded: "Weed competition rather than soil depletion is the factor primarily responsible for the lessened yield of the second-year milpa (cornfield). It seems equally clear that tree growth after abandonment of a milpa functions primarily in choking annual weeds rather than in restoring depleted soil fertility." A similar conclusion was reached by Joachim and Kandiah (1948) after studying the effects of shifting cultivation on soils in Ceylon. Pelzer (1945) cited grasses and weeds as the main cause for abandoning land in the Asiatic tropics, and Freeman (1957) believed: ". . . weed growth more than any other single factor, is responsible for crop failures" on shifting cultivated land of the Iban of Sarawak.

The controversy on the effects of invasion of grasses when rain forest is cleared for crops has raged for many years. Bartlett (1956) described the different patterns in the tropics based on a survey of the literature and his personal experience. In addition, his annotated bibliographies (Bartlett, 1955, 1957) brought together much of the widely scattered information available on changes in the vegetation brought about by periodic or sporadic burning. Commenting on whether grassland or trees will occupy an abandoned cultivated site in the forest, he said:

Vegetational history shows that, in general, deserted tropical agricultural clearings not burned over after abandonment, if surrounded by damp forest, quickly become seeded and reforested by quick-growing, light-loving trees. . . . The most rapid deflection from normal ecological succession occurs in clearings which border regularly burned grassland. Here deflection of the succession to grassland is almost certain.

In Central America many authors hypothesized that shifting cultivation was limited by the length of time the land could be kept free of grasses. They argued that once grasses became established in clearings, labor for eradication was too arduous and consequently the shifting cultivator moved on to a new forested site. Forest may then eventually crowd out the grass. Morley (1956), one of the foremost authorities on Mayan civilization, was a strong proponent of the theory that the Mayan Empire collapsed when grass crowded out the bush in lands under shifting cultivation.

One of the earlier and more vociferous proponents of the hypothesis that grass was the main limiting factor in shifting

cultivation in Guatemala was Cook (1908, 1921) who maintained that the replacement of forest by grassland set a natural limit to the period of agricultural occupation in a system of shifting cultivation and, consequently, that grassland was a foregone conclusion of repeated shifting cultivation. Lundell (1937) agreed with Cook that fires destroyed many large forest areas in Guatemala. After watching fires extend the savannas of Central Petén during the very dry year of 1933, he concluded that such extreme climatic conditions coupled with shifting cultivation led to the denudation of forest and the subsequent formation of grasslands in that region. However, Lundell (1940) in another paper described large areas of ancient terraces in British Honduras which he concluded were indicative of continued occupation of land under at least a semipermanent agriculture. It would appear that under these conditions a grass succession did not force the population from the area.

Arguments against the theory that the Mayan system of shifting cultivation finally failed because the land was invaded by grasses were provided by Thompson (1954). As evidence he said:

It is true that grass will appear in cleared forest land if those patches are kept free of trees and shrubs for several years, but the Maya abandoned their clearings after one or two seasons' use, and in that short time grass can not establish itself. I have noticed that verges of roads cut in the forest and used for several years to extract mahogany are often of grass, but when those roads are abandoned, they revert rapidly to forest. Some years ago I was in Chicchanha, an important Maya town in southern Quintana Roo until its abandonment in 1852. During its occupation the main plaza and the streets must have been under grass, as in any other Maya town. Yet, when I visited the town, it was entirely covered with deep forest, to a layman

indistinguishable from the surrounding virgin forest. . . . There are no savanna lands around the great concentration of ceremonial centers in the northern Petén, or around Quirigua with its deep soil, or along the Usumacinta.¹

Further support to Thompson's arguments was given by Hester (1954) who stated:

There are no perpetual grasslands in the lowland Maya regions occupying soils which otherwise would be well suited to maize agriculture. It cannot be said for this part of the world that grasses have invaded, and become ineradicably established upon agricultural lands as a consequence of shortcomings of primitive agricultural techniques.

Soil fertility

General exhaustion of soil fertility has been cited by many writers as the primary reason for the abandonment of fields under temporary cultivation. Obviously this depends on whether one is dealing with old, highly-leached soils or relatively young soils derived from basic volcanic or sedimentary parent materials. The staff of FAO (1957), in a general article on shifting cultivation, emphasized the point that soil fertility is the most important determinant of the length of time that land can be cultivated. They said:

It seems to be established that the factor which keeps people at the level of shifting cultivation is in the first place the rapidity with which tropical soils lose their fertility (i.e., their lack of retaining capacity of plant nutrients) and undergo undesirable

¹Thompson suggested that the collapse of the Mayan Empire was due to revolts by the peasant classes against the non-producing hierarchy.

changes in physical conditions. These difficulties can be split into several factors--low absorption capacity for exchangeable bases of the soils' clay fractions, the tendency of these clays to immobilize phosphates, the heavy percolation rate of tropical rains through generally porous soils and the resulting leaching of plant nutrients, the rapid destruction of organic matter by bacterial action under conditions of high temperatures, and so on.

Accordingly, the fallow then restores soil fertility. In areas of rich stable soils a continuous cultivation is possible.

A dismal agricultural picture was painted of Africa by Harroy (1949) who blamed intentional firing of land for the dehydration of surface soil colloids, leaching out of salts, destruction of organic matter, modification of soil pH, and alteration of microfauna and microflora. Bartholomew et al. (1953) hypothesized that "depletion of available nutrients may well be among the most important" causes for the decline in productivity of lands under shifting cultivation.

Richards (1952) in a general discussion, related the entire shifting cultivation cycle--forest - cleared field - forest--to the impoverishment and subsequent restoration of soil fertility. Piquier (1953), in Madagascar, concluded that two or more seasons of cropping so exhaust the soils of clearings devoted to shifting cultivation that reforestation or regeneration is of doubtful success.

Many writers, after careful study, have arrived at the opposite conclusion: depletion of soil fertility is not of paramount importance in shifting cultivation. As stated earlier, Joachim and Kandiah (1948), after an intensive investigation of the effects on soils by shifting cultivation in Ceylon, concluded that the main limiting factor was weeds, and not the depletion of soil fertility. Their conclusions were:

These investigations have indicated that while there are some losses of organic matter, nitrogen, and mineral nutrients as a result of chenaing land, these would occur under any system of rotational cropping on new jungle land and are not such as would render the land unsuitable for further profitable cultivation with a succession of annual crops.

From work in Malaya, Coulter (1950) concluded that physical rather than chemical factors contributed to the degradation of tropical soils that were cleared of rain forest.

In Central America, much shifting cultivation occurs on very fertile soils and many investigators have attributed declines in crop yields to causes other than lack of soil fertility, although one worker (Lundell, 1937) wrote that "apparently continued rotation leads to complete soil exhaustion" in northern Guatemala. However, Emerson (1953), after investigations in Yucatán, concluded that: "One with an agronomic background finds it difficult to believe that milpas, after two crops of maize, have been abandoned because of soil depletion, and equally difficult to conceive of soil fertility, once depleted, being restored by a few years of tree growth." Morley (1956), in essential agreement with Emerson, said:

That soil exhaustion is not the chief factor responsible for this decrease in the yield of Maya cornfields today has been demonstrated in the Carnegie Institution's experimental milpa at Chichén Itzá (Yucatán). After the harvest each successive year, specimens of soil have been taken from this cornfield and over a period of ten years, the annual analyses of these specimens have shown no appreciable decrease in the amount of necessary nitrogenous salts, nor a sufficient amount of deterioration in the chemical composition of the soil to account for the diminishing yearly yield.

More recently Hester (1954) after studying soils in the Maya area, concluded that: " . . . there was no pronounced indication of soil exhaustion. On the basis of soil analyses, present agricultural techniques could be continued indefinitely." The soil sampling technique was described by Hester in the following words: "Samples were gathered wherever possible at intervals of ten kilometers, measured along highways radiating from Merida, . . . Other samples were taken at places away from paved roads, . . . " Depth of sampling and whether single or composited samples were used is not stated. Fifty soil samples were analyzed at the University of California. Soils were extracted with ten per cent sodium acetate at pH 6.0. Apparently, phosphorus, potassium, calcium and magnesium were determined in the extract. In addition, soluble salts, pH, moisture capacity, total nitrogen, ammonia nitrogen and nitrate were also measured. Thompson (1954) pointed out that: "Quirigua was one of the earlier cities to cease functioning in the Maya Empire although the alluvial soil there is very rich." Actually the soil of Quirigua is probably not as good for crop production as Thompson would have us believe. The writer is of the opinion that Charter (1940), after surveying soils in British Honduras, gave the most accurate summation of the basic limitations of shifting cultivation in the Maya region.

He said:

Decline from soil fertility and competition from weeds are equally important factors in the decline in yields of and under shifting cultivation. The soil is actually rich enough to support an intensive agriculture with weed control and a small amount of fertilizer (which is necessary under intensive agriculture).

Literature can be drawn from many sources, not directly related to shifting cultivation, on the effects of burning and forest-clearing on particular soil properties. Pertinent literature for each specific property will be discussed under separate headings.

Nitrogen and organic matter.--One common misconception of tropical soils is that all nitrogen and organic matter contents are low. Originally, Jenny (1930) hypothesized that soil organic matter contents decreased with increasing temperatures, rainfall remaining constant. His survey of the United States showed that the soils highest in organic matter were in the northern portion and values decreased progressively southward. Several writers, among which were Mohr and Van Baren (1954), extrapolated these data and concluded that organic matter contents for tropical areas must be even lower than in temperate climates. This misconception was probably responsible for the erroneous ideas that prevailed for a long time, that all tropical soils are low in organic matter. However, Smith et al. (1951), after investigations in Puerto Rico, proposed that the concept of Jenny be limited climatically to temperate regions by the frost-free boundary. They suggested that the absence of killing frosts favor the building of organic material by green plants much more than it favors destructive microbiological activity within the soil. Data from many areas support their assumption.

High soil organic matter contents in the tropics correspond to areas of high rainfall with no marked dry season and to elevated regions with cool temperatures. Very high soil nitrogen values in

the Western Hemisphere have been reported from Hawaii, British Honduras, Costa Rica, Colombia and Puerto Rico (Dean, 1930; Hardy et al., 1935; Jenny et al., 1949; Suarez de Castro and Rodriguez, 1955; Schauffelberger, 1956; Smith et al., 1951). A few studies where an extreme paucity of organic matter has been reported in the tropics were from areas (especially in Africa) either with less than eighty inches of rainfall, or with several very dry months during the year.

Relationships between soil organic matter accumulation and climate and elevation have been thoroughly studied for several areas of the tropics, and general levels of organic matter were much higher than would be expected from similar studies in temperate zones. Soil organic matter increased with an increase in rainfall if temperature remained constant (Craig and Halais, 1934; Birch and Friend, 1956; Dean, 1937; Schauffelberger, 1956). Jenny et al. (1948) suggested that this increase was logarithmic. Soil organic matter also increased with a decrease in temperature, which generally occurred at higher elevations (Ramirez, 1951; Dean, 1937; Schauffelberger, 1956; Jenny et al., 1948). However, Birch and Friend (1956) found the effect small compared with that of rainfall.

The high rate of production of tropical vegetation is undoubtedly one of the most important factors in the high levels of soil organic matter recorded in the humid tropics. Measurements of organic matter production are available from several tropical areas and indicate that rates are much higher than in temperate climates. Suarez de Castro and Rodriguez (1955) calculated the litter returned annually to the soil in

Colombian coffee plantations was between 4.6 and 13 tons per hectare. Jenny et al. (1949) estimated the annual production of organic matter in the form of leaves and twigs in Costa Rican and Colombian rain forests was 9.4 to 13.2 tons per hectare and that the time to reach near equilibrium of the forest floor was less than a decade. Laudelout and Meyer (1954), for the Belgian Congo, reported organic matter production was from 12.3 to 15.3 tons per hectare and the quantities of mineral nutrients involved in the annual cycle were similar to the quantities involved in temperate regions, except for nitrogen which was 6 to 10 times greater in the equatorial forest. Orchard and Darby (1956) estimated the enrichment of veld soils under leguminous wattle trees was 180 ± 40 pounds of nitrogen per acre per annum over a period of 30 years. Evidently, additions of organic matter are of sufficient magnitude in the humid tropics to maintain soil humus at a high level although decomposition is rapid.

The clearing or cultivation of forest soils appeared to result inevitably in lower organic matter values. On forest soils of Trinidad, Duthie et al. (1936) found that organic carbon, nitrogen, and the C:N ratio immediately decreased to a depth of two feet after forest land had been cleared. Richards (1952) interpreted the results of Duthie's investigation as indicating that effects of forest clearance alone on organic matter are very transient but effects of cultivation over a long duration of time are much more lasting. In a study of 29 locations in Georgia, Giddens et al. (1957) reported that cultivation lowered the average content of organic matter from 3.29 per cent in forest soils

to 1.43 per cent for cultivated areas. Coulter (1950) reported that the average nitrogen content of virgin rain forest soils in Malaya was considerably higher than that of cleared soils. However, not all rain forest soils were high in organic matter, nor all cleared fields low. The average nitrogen content of forest soils was 0.240 per cent whereas the average value for plantation soils was 0.155 per cent. Coulter concluded that: "It would appear that, with limitations, the nitrogen content of the soils could be utilized as one criterion for following the rejuvenation of a degraded soil." In Ghana, forest soils after clearing lose organic carbon in the 0-12 inch layer at a rate of 3 per cent per year (Nye, 1958). In Madagascar, forest clearance appeared to destroy organic matter and humus and to check its subsequent accumulation without necessarily reducing available nitrogen (Riquier, 195).

Despite almost universal agreement about the effects of clearing on soil organic matter, the effects of burning appeared to be much more controversial. Heyward and Barnette (1934), Klemmedson et al. (1958), Meiklejohn (1955) and Suarez de Castro (1957) found that burning either increased soil nitrogen or had little effect. Meiklejohn believed that burning the vegetation might kill the nitrifying bacteria in the soil below the burn and so lead to a conservation of soil nitrogen. Vlamis et al. (1955), using pot tests, reported that the nitrogen supplying power of the soils investigated was increased up to eight-fold by burning. However, Joachim and Kandiah (1948) reported losses of nitrogen and organic matter as a result of burning in Ceylon.

The main effect of forest clearance on soil organic matter is through the loss of a constant source of fresh litter which continuously accumulates on the soil surface and is rapidly attacked by the soil organisms. Furthermore, the removal of shade probably leads to a faster oxidation of soil organic matter as a result of higher surface temperatures from increased sunlight. The maintenance of a large supply of organic matter in most tropical soils under continuous cultivation for a long period of time is doubtful. Lugo-Lopez et al. (1956) found that cultivated latosols in Puerto Rico seemed to reach an equilibrium at a maximum of 3 per cent organic matter irrespective of treatment with organic materials. Suarez de Castro and Rodriguez (1955b) reported that the response of coffee soils in Colombia with 3 per cent organic matter to additions of organic materials was of the same magnitude as temperate climate soils containing 1 per cent organic matter. They suggested that soils containing less than 3 per cent organic matter were deficient in this respect. *

The ratio of carbon to nitrogen is often useful to predict either the amount of immobilization, or rate of release, of mineral nitrogen. Much importance is attached to the values of C:N ratios as indicators of whether organic additions to soils will release or tie up mineral nitrogen. The latest views were summarized by Russell (1950) who said that easily decomposable plant material when added to the soil will release inorganic nitrogen if the C:N ratio of the added material is less than 25 and will remove inorganic nitrogen if it is much above 50 in tropical regions. Black (1957) placed the critical C:N limits

between 15 and 33, and Harmsen and Van Schreven (1955), in a review of literature, placed it between 20 and 25. Hardy (1946a) concluded that for comparable C:N ratios more nitrate was produced in the wetter West Indies than in drier Queensland. Thus far, for tropical areas, the C:N ratio has been of little value or use in predicting responses to applied nitrogen, though Hardy (1946b) successfully demonstrated that C:N ratios, in the West Indies, below 10.5 produced bolting in cotton. Above that value, less nitrogen was mineralized and a normal cotton crop was produced.

Investigators in many tropical areas have found interesting relationships between soil C:N ratio and environment. In Mauritius, soils of wetter areas contain more organic matter with a wider C:N ratio than those of dry areas (Craig and Halais, 1934). Dean (1937) concluded that the C:N ratio of soils in Hawaii increased with increasing rainfall but was not significantly related to elevation. However, Mohr and Van Baren (1954) assumed that the C:N ratio would be higher at higher altitudes than near sea level. They cited H. J. Hardon's work in Indonesia, which indicated a positive correlation with temperature, a negative one with pH, and no correlation with moisture and soil type. Jenny et al. (1948) confirmed Hardon's observations with investigations in Colombia; but Ramirez (1951), working in the same country, found diminishing C:N ratios with increasing altitude.

Nitrification under the favorable temperature and moisture conditions which are present in the tropics usually proceeds at a

high rate. However, the very large quantities of nitrate nitrogen found in many tropical regions has baffled investigators, for it would appear then that sources of nitrifiable nitrogen are inexhaustible. Greenland (1958) probably correctly diagnosed the situation when he said:

While precise data on soil conditions under tropical forests are lacking, it is almost certain that they are such that absorption of nitrate by micro-organisms, denitrification and leaching will all proceed quite rapidly. The high levels of nitrate most probably represent an equilibrium level typical of a rapid cycle in which relatively large additions of nitrifiable organic material and of newly fixed nitrogen, and correspondingly large losses of nitrate by leaching and denitrification occur.

Tropical workers for many years have noted the seasonal release of nitrates in soils exposed to wet and dry seasons. Generally, at the onset of the rainy season, a very rapid increase in nitrification occurs which lasts approximately six weeks (Griffith and Manning, 1949; Greenland, 1958; Hagenzieker, 1957; and Birch, 1958). Greenland (1958) has suggested that nitrifiable organic matter increases during the dry season when crop residues and dead micro-organisms accumulate in the dry soil. This organic matter is then available for nitrification processes at the beginning of the rainy season. Thus, the production of nitrate nitrogen is usually very high immediately after an extensive dry season. One might conclude that crops should be grown as early as possible after rains commence in areas with a marked dry season to coincide with the period of maximum nitrate production.

In the humid tropics with a mild dry season, a slightly different picture can be drawn which might be exemplified by the data of

Hardy (1946a). In Trinidad with a rainfall of 68 inches, Hardy found that maximum accumulation of nitrates occurred during the mild dry season. The accumulation of nitrates began when the amount of evaporation exceeded the rainfall; usually when the rainfall of the previous 28 day period was below 4.0 inches. It is possible, as Greenland (1958) hypothesized, that the soil moisture during the dry season may be high enough so that nitrification is not impaired (Greenland found considerable nitrification at moisture contents as low as 4 per cent). Greenland concluded that nitrates accumulate under these conditions during the dry season and are rapidly leached at the beginning of the wet season. Since nitrification has continued during the dry season, little nitrifiable organic matter is left to support a high rate of continued nitrification during the rainy season.

Investigators in the tropics have presented conflicting evidence of the effects of shade on mineralization of soil nitrogen. Harmsen and Van Schreven (1955) concluded from a literature survey that sometimes too high temperatures may suppress mineralization.✓ However, Griffith and Manning (1949), in Uganda, reported that during the rainy season nitrate accumulation on bare soil was much higher than under a grass mulch on medium textured soils. Mills (1953), in the same area, recorded nitrate accumulations up to 200 ppm. on bare fallow soil, and only 10 ppm. on shaded and/or mulched soil. Greenland (1958), in contrast to Griffith's and Mill's work, found very little difference in nitrate levels between shaded and unshaded bare

fallow plots on sandy soils. He believed that in Griffith's work the unshaded plot would have been baked hard by the sun and leaching would have been reduced, so that much higher levels of nitrate were found. Since Greenland's work was on coarse, sandy soils the effect of sun on soil structure would have been small. Jacquemin and Berlier (1956), however, found that nitrification was almost nil in a bare soil on the Ivory Coast. They indicated that the low nitrifying power of forest soil is increased by clearing but will soon drop to zero if the soil is kept bare. Apparently, some of the controversy on the effect of shade on mineralization of soil nitrogen is caused by the effect of shade on soil structure and infiltration capacity occurring at the same time.

Cation exchange capacity and base saturation.--Cation exchange capacities of tropical soils vary widely but are generally considered to be low. A range from 2 to 64 me. per 100 g. has been reported for Puerto Rican soils (Bonnet et al., 1951), and a range of 2.8 to 127 me. per 100 g. has been found in Hawaii (Kanehiro and Chang, 1956). Organic matter may contribute a large part to the exchange capacity of tropical soils. Abruña-Rodríguez and Vicente-Chandler (1955) reported values for the exchange capacity of organic matter of some Puerto Rican soils generally between 100 and 150 me. per 100 g. and accounted for about 25 per cent of the total exchange capacity of kaolinitic soils with widely varying pH values.

Base (or cation) saturation has been related to several environmental features. Mehlich (1941) was able to show that the

relationship between base unsaturation and pH was characteristic of the type of clay mineral present, with the exception of montmorillonite and hydrous mica which had similar curves. Kanehiro and Chang (1956) found an overall decrease in base saturation with increasing rainfall for Hawaii. Laudelout and Meyer (1954) reported that the cation composition of plant material returned to the soil was related to "the degree of cation saturation of the soil adsorbing complex" in the Belgian Congo.

Coleman et al. (1958) and Coleman et al. (1959) discussed the concept of permanent charge and pH-dependent charge components of the exchange capacity. Permanent charge was defined as the sum of exchangeable cations, including aluminum displaced on leaching with a neutral salt solution. The pH-dependent charge was regarded as the amount of exchange acidity remaining after neutral salt leaching (mainly originating with weakly ionized, acidic radicals). They felt that cation saturation based on permanent charge was preferred to saturation based on exchange capacity as a concept of soil fertility.

Soil acidity.--Well drained, mature soils of the humid tropics are highly acid because most of the exchangeable bases have been leached from the profile by the heavy rainfall. Nevertheless, many writers have reported that tropical crops are able to grow well at pH values considerably below those required for temperate crops. Richardson (1951) said that in areas with an approximate pH of 5, no tropical or subtropical crops other than peanuts are likely to need lime. Russell (1950) believed that crops tolerate acidity better in

moist than in dry climates. He gave as a reason: " . . . for a given soil pH as measured by shaking up in water, the acidity of the soil solution will rise as the soil becomes drier, and the root system of the crop may suffer accordingly."

The acidity of soils under a heterogeneous forest cover is usually quite variable. Ovington and Madgwick (1957), in England, were able to grade a large number of tree species according to their effect on soil acidity. Kellogg¹ cautioned that the pH under tropical forest trees is highly variable. He reported that soil pH values in the same mixed forest in Africa may vary from 4.5 to 7, depending on whether the samples are collected under sulfur accumulators or under calcium accumulators.

Burning generally increases the pH of the topsoil because ash from vegetation contains various amounts of the oxides of calcium, magnesium, potassium and sodium. The reaction of these cations with the exchange complex increases the percentage base saturation and reduces soil acidity (increases soil pH). Investigators, in widely separated areas have reported the decrease in surface acidity which accompanies burning of vegetation (Evers, 1954; Heyward and Barnette, 1934; Isaac and Hopkins, 1937; Janse et al., 1955; Suarez de Castro, 1957; Vine, 1953, 1954; Duthie et al., 1936).

¹Personal communication from Dr. C. E. Kellogg, Assistant Administrator for Soil Survey, United States Department of Agriculture Soil Conservation Service, Washington, D. C., dated October 31, 1955.

Several investigators (Maher, 1949; Edelman, 1949; Middelburg, 1952; Peele, 1940) have found that the correction of soil acidity by liming is of doubtful merit in the tropics because it promotes trace element deficiency, humus decomposition and structural deterioration of latosols. Middelburg (1952) and Schuffelen and Middelburg (1954) found that liming decreases permeability of latosols in Indonesia until a pH of 7 is reached, above which permeability increases again with further additions of lime. They also found that liming reduced minor element availability except molybdenum and increased nitrogen loss. On the Cecil clay loam, in the southern United States, applications of calcium in the form of carbonate, chloride or hydroxide decreased saturated permeability, (Peele, 1940). In Colombia, although liming increased soil nitrate content, Suarez de Castro and Rodriguez (1956) suggested that growth results indicated it was inadvisable to use lime, especially at heavier rates. Apparently, since many tropical crops do tolerate very acid conditions, liming soils to decrease soil acidity should be prescribed with great caution.

Aluminum.--Many of the negative effects of extreme soil acidity on crop growth can probably be attributed to the large amount of aluminum which comes into solution at low soil pH. Soil pH values below 5.5 indicate aluminum is present in the exchange complex, and at values below 5.0 aluminum is one of the major exchangeable ions (Coleman, 1958). Arnon (quoted by Allaway, 1957) demonstrated that plants, growing in solution, are not greatly affected by pH values from 4 to 9. However, Coleman et al. (1958) found that root growth

was largely inhibited if soil pH was below 5.5 and if the soil contained more than about 90 ppm. of exchangeable aluminum. Usually, aluminum toxicity was indicated by a stunting of the root system.

Grasses, such as corn and sugar cane, are sensitive to high amounts of exchangeable aluminum, whereas tea, coffee and possibly cacao can withstand conditions associated with high acidity (Hardy, 1956).

Magistad (1925), working with solution cultures, reported that aluminum exerted a pronounced toxic action when present in concentrations of 50 to 100 ppm. in cultures at pH 4.2 and 4.0, respectively. Corn was more sensitive than other crops and growth was seriously affected at pH 4.7.

Cases of aluminum toxicity are often reported on highly leached acid soils of the humid tropics. Duthie and Bourne (1939) found that aluminum toxicity, caused by the use of acid fertilizers on sugar cane in British Guiana, was particularly noticeable at pH values below 4.7. They recommended flood fallowing to remove soluble salts and raise the available calcium content of the soil. Nguyen-Cong-Vien (1953) suggested that the beneficial action of both mulch and calcium phosphate on sterile patches of soils in Indochina could be attributed to the immobilization of free aluminum ions. Coarse-textured soils in Uganda with pH values near 4.0 contained as much as 460 ppm. available aluminum (Chenery, 1954). Such acid soils were found to occur in regions with annual rainfall in excess of fifty inches.

Potassium and sodium.--In general, potassium deficiencies are not widespread in the tropics. Although levels in the exchange complex may not be high, the rapid rate of weathering which occurs in the humid tropics suffices to release enough potassium from potash-bearing minerals to supply plant needs. Even though slightly weathered rhyolitic soils of Sumatra may contain only 78 to 195 ppm. exchangeable potassium, crops do not respond to applications of potash (Van der Marel, 1947). Likewise, Nye and Stephens (1958) reported that savanna soils of Ghana gave no response to potassium fertilization during eight years of cropping though they contained as little as 40 ppm. exchangeable potassium. The lack of response to potassium in Sumatra and Ghana has been attributed by these authors to the release of sufficient potassium from the rapid weathering of minerals in a hot, humid climate.

Generally, the potassium content of topsoil will increase after burning (Suarez de Castro, 1957; Focan et al., 1950) because cations are released from oxidation of vegetative material. In soils, cleared by burning, potassium is not leached as rapidly as either calcium or magnesium (Hardy, 1956; Mehlich and Reed, 1945; Suarez de Castro and Rodriguez, 1958). One reason is that a decrease in exchange capacity (which clearing produces) favors the adsorption of monovalent ions at the expense of the divalent ions (Wiklander, 1955). Furthermore, as a soil becomes more acid (by leaching), potassium ions are held relatively more strongly than calcium ions (Russell, 1950).

Although some plants are able to use sodium as a partial substitution when potassium is deficient, there is considerable variation among plants in their behavior. Corn tends to exclude sodium and shows no response to fertilizer applications even when potassium is deficient (Black, 1957).

Calcium and magnesium.--A large part of the literature pertaining to calcium investigations in tropical soils is concerned with the practice of liming. No effort has been made in most cases to separate the effects of calcium nutrition from the effects of soil pH changes. For this reason, literature on liming has been included in the section on soil acidity.

Evidences of magnesium deficiency have been reported from several tropical areas (Kandiah and Rodrigo, 1954); Ferrand, 1957; Hewitt and Bull, 1956; Robinson and Chenery, 1958). However, comparatively very little work has been done on nutritional responses to calcium and magnesium in the tropics.

Manganese and zinc.--Analyses of exchangeable manganese in soils are available from several tropical regions (Biswas, 1951, 1957; Hopkins et al., 1944; Koch, 1946). Vlamis (1953) compared toxicity of manganese with aluminum in solution cultures and found that aluminum toxicity occurred at 1 to 2 parts per million (ppm.) whereas manganese was toxic at concentrations of 10 to 15 ppm. Black (1957) said that corn may tolerate over 15 ppm. manganese in displaced soil solutions.

Thorne (1957), in a review of zinc nutrition, stated that zinc in the soil is usually associated with residues of organic materials and greatest concentrations are found in leaf litter. Investigators have generally associated zinc deficiencies with soils that have a pH of 6.0 or higher and a sandy texture. Fruit crops are most commonly affected but corn probably suffers the most of annual crops from lack of this nutrient. Gall and Barnette (1940) reported toxic levels of replaceable zinc for corn on Florida soils was between 225 and 450 ppm. on Norfolk sand, between 248 and 372 ppm. on Orangeburg fine sandy loam, and between 528 and 703 ppm. on a Greenville clay loam.

Shifting cultivation is perhaps a good way of avoiding zinc deficiency without the use of chemical fertilizers. Rogers et al., (1939) found that native weeds, on zinc deficient soils of Florida were far better collectors of zinc than planted crops. Native weeds contained on the average 140 ppm. of zinc in their dry matter whereas a cover crop of crotalaria contained 4 to 11 ppm. They suggested that the best way of preparing land for corn is to allow native weeds to cover the land, and then plow them in before corn is planted. The forest fallow in shifting cultivation would probably perform the same function.

Phosphorus.--Phosphorus has always been one of the most difficult elements to analyze in tropical soils. Extraction methods, developed for less acid and less highly leached soils of temperate climates, have not been correlated very successfully with crop

responses in the tropics. Birch (1952), in Kenya, found a more significant correlation between phosphate responses and percentage saturation of the cation exchange capacity than with amounts of acid-soluble, adsorbed and water-soluble phosphate in soils. Nevertheless, in Ghana, Nye and Bertheux (1957) obtained a better indication of phosphate responses on sorghum, corn and peanuts with the Bray "quick test" extraction than with more complete types of phosphorus extractions such as the acetic acid-soluble, the sodium hydroxide-soluble inorganic forms, and the organic form. Lopez (1958) reported a very significant correlation between the strong Bray extraction ($0.03N$ NH_4F in $0.1N$ HCl) and corn yields in fertilizer trials in Colombia. The method of Bray and Kurtz gave the most significant correlation with field responses to phosphorus fertilization on acid soils in a survey of methods used by laboratories in the United States (Anonymous, 1956).

Phosphorus, next to nitrogen, has been found to be lacking the most in tropical crop production in general, although Nye and Bertheux (1957) said that in Ghana and other parts of West Africa, phosphorus is the most serious nutrient deficiency. Nye (1958), using Bray's rapid extraction procedure, found an average of 5 ppm. of phosphorus in the 0 to 15 cm. layers of eleven undisturbed forest sites in Ghana, but pointed out that on sites disturbed by habitation very high values, sometimes over 100 ppm. phosphorus, were obtained. Lopez (1958) extracted 17 to 20 ppm. phosphorus with the strong Bray extraction procedure on soils in Colombia to which no phosphorus had been added; heavily fertilized soils had values as high as 70 ppm.

Usually in well-leached, tropical forest soils the amount of acid-soluble phosphorus is much higher in the topsoil and decreases rapidly with depth (Kellogg and Davol, 1949; Endredy and Montgomery, 1954; Nye and Bertheux, 1957). This is in contrast to less well-leached temperate soils where the phosphorus generally increases with depth (Nye and Bertheux, 1957). Since phosphorus is closely linked to the organic matter cycle, the greatest concentration in highly weathered soils will correspond to the zone of accumulation of organic matter. In Ghana soils, the acid-soluble phosphorus is predominant in surface soil horizons and is definitely correlated with the total nitrogen content (Endredy and Montgomery, 1954; Nye and Bertheux, 1957).

Nye and Stephens (1958) pointed out that in forest soils much of the available phosphorus for crops was maintained by release of phosphates from organic phosphorus during the decomposition of organic matter. They suggested that the rate of oxidation is about the same as soil organic matter. In continuous fertilizer trials they found the rate of loss of organic carbon to be 3 per cent per year in forest for the 0 to 30 cm. horizon (the horizon from which they observed corn obtained 90 per cent of its phosphorus requirement). They calculated that in forest soils, with about 400 pounds per acre of organic phosphorus in the top 30 cm., the release per year was 12 pounds of phosphorus or the equivalent of 150 pounds of single superphosphate fertilizer. Much of the value of resting fallow was attributed to its role in replenishing these supplies of available phosphorus in the topsoil.

When vegetation is burned to clear land for cropping, much soluble phosphorus is added to the soil. Vlamis et al. (1955), in pot tests, found that the phosphorus content of burned soil increased so as to give ten times higher yields unless partially fixed by the soil. In Colombia, the phosphorus content of corn leaves was increased by burning (Suarez de Castro, 1957), and, in California, the phosphorus content of burned pastures was double that of unburned pastures (Hart et al., 1932). Burned plots of green manure (Stizololobium) in Nigeria always gave better growth of corn during the first few weeks than plots where the green manure had been dug-in. This was attributed by Vine (1953) to the fact that the phosphorus in the green manure was made more readily available by burning.

Soil structure.--The importance of soil structure in crop production has been well-recognized by a few writers. Baver (1956) said: "Soil structure is the key to soil fertility!" Martin (1944) concluded from field observations in Uganda that: " . . . it was the physical rather than the chemical condition of the soil that determined fertility."

Nye and Stephens (1958) described the effects of shifting cultivation on soil structure in the following way:

Under a forest fallow the surface horizon develops an excellent physical condition. The surface of the soil is protected by the litter, the fauna keep the soil open, and even on the light soils a weak crumb structure develops.

The weak structure developed under fallows is rapidly destroyed by cultivation, and to preserve it

the less the soil is cultivated the better. The traditional farming practice in the forest, which involves a minimum of soil disturbance and a good soil cover . . . preserves structure and organic matter. . . .

Most tropical soils are very well structured, primarily due to the influence of ferric hydroxide (which dries almost irreversibly) on the aggregation of soil particles (Baver, 1956). Lutz (1934) suggested that the role of iron in aggregation was probably that of flocculation and cementation of soil aggregates. Russell (1959) mentions this in describing tropical soil structure and its implications. He related soil structure to

. . . the binding together of soil particles into fairly sponge-like crumbs by precipitated and fairly dehydrated iron oxides. This iron oxide gives a red color to the soil, but not all red soils have this very desirable structure. When it does occur, as it does for example, in parts of the Kikuyu reserve in Kenya one can practice an intensive system of nearly continuous cropping in which little use is made of resting crops or farmyard manure without the complete collapse of soil structure or crop yields; a system which would fail completely for example, on soils derived from granite low in iron.

The effects of burning on soil structure have not been extensively investigated and no generalities can be derived from the few results available. Rodriguez (1952) found that texture was unaltered by burning in Colombia, but that structure was markedly and cumulatively improved with consequent improvement in noncapillary porosity, aeration and permeability. Burning increased the percentage of aggregates larger than 0.5 mm. from 35 per cent to 42 per cent and decreased the amount of aggregates smaller than 0.25 mm. from 50 to

42 per cent and decreased the amount of aggregates smaller than 0.25 mm. from 50 to 43 per cent. When twice as much brush was burnt on the soil these differences were more marked. He suggested that the large increase in yields he obtained on burned plots was probably due to the improved physical condition rather than any increases in fertility. Dryness and Youngberg (1957), studying the effects of logging and slash burning in Oregon, found that structure was adversely affected only in the most severely burned areas where there was a significant decrease in the amount of clay present and a 20.6 per cent decrease in the degree of aggregation. They concluded that since only 8 per cent of the soil surface was severely burned, detrimental effects were not appreciable. After investigations in Ceylon, Joachim and Kandiah (1948) reported: "There are no appreciable changes in soil structure as a result of chenaing (clearing) land."

Effects of burning on infiltration have been more thoroughly studied than effects on soil structure per se. Several studies (Burgy and Scott, 1952; Scott, 1956; Scott and Burgy, 1956) have shown that burning increased infiltration rates of the soils studied except in the case of intense burning of a wet soil surface. However, Burgy and Scott (1953) pointed out that run-off from a burned area exceeded that from an unburned area for a period of two years. They proposed that this was caused by a lessened friction factor to overland flow whenever rainfall intensity exceeded infiltration capacity. Suarez de Castro (1953) found burning increased infiltration on two plots studied in Colombia. However, Budowski (1956) quoted F. W. Freise,

who worked in Brazil, as writing that infiltration rates were approximately twice as slow after forest had been felled and burned than before.

The bulk density (apparent density) of soil is a good measure of soil structure. The bulk densities of clay, clay loam, and silt loam surface soils normally may range from 1.00 to as high as 1.60 gms. per cc., depending on their condition (Lyon et al., 1952). However, forest soils with high organic matter contents in the surface horizons may be much lower. Values for the A₀ horizon of forest soils are usually about 0.2 and those of the A₁ horizon are commonly less than 1.0 (Lutz and Chandler, 1946). Many tropical soils, because of their high state of aggregation may also have low values. On Hawaiian sugar cane lands, bulk densities of surface soils average around 1.0 and values of 0.43 and 0.58 have been reported (Shaw and Swezey, 1937). Hydrol humic latosols of Hawaii generally tend to have bulk densities ranging from 0.1 to 0.7, though they average approximately 0.5 (Sherman, 1957). Trowse (quoted by Baver, 1956) found bulk densities ranging from 0.4 to 1.0 on Hawaiian soils derived from volcanic ash.

The effects of bulk densities and soil compaction on plant growth have been studied by several workers. Viehmeyer and Hendrickson (1948) related limiting bulk density values to different textures. They found that "threshold densities above which sunflower roots did not enter seemed to be about 1.75 for the sands and varied from about 1.46 to 1.63 for the clays." Investigations in Louisiana (Scarsbrook et al., 1952) indicated that compacted plow pans with bulk densities

of 1.35 to 1.40 seriously restricted the penetration of cane roots. Volk (1954) suggested that plowsole pans in Florida with densities higher than 1.8 should be given special attention. Bertrand and Kohnke (1957) found corn roots did not penetrate a subsoil compacted to a bulk density of 1.5, but they grew profusely in subsoil with a bulk density of 1.2. For the tropics, Lugo-Lopez and Acevedo (1956) showed that compaction by heavy tractor traffic increased bulk densities of Puerto Rican soils from 1.14 to 1.33 and reduced quick drainage characteristics.

Erosion.--Normally, with comparable slopes, soils in the tropics are less erosive than those in temperate regions. But among the most productive soils in the tropics are those on steep slopes, kept fertile by natural erosion of the leached surface layer, or on young volcanic deposits, which are often hilly. Indeed, Pendleton (1956) ascribed one of the major difficulties of large, flat humid tropical areas to too little erosion of the highly leached surface soil. Ives (1951) recognized leaching as more important than erosion in Costa Rica and recommended that practices for the establishment of organic matter to minimize leaching in surface layers would be more fruitful than erosion control. Smith and Abruna (1955) thought that Puerto Rican soils appeared to be two to three times as resistant to erosion as soils in the temperate zone. Although tropical soils are much more resistant to erosion than temperate soils, the relatively higher rates of rainfall within the humid tropics make erosion an ever-present menace on steeply sloping lands.

Detailed studies of the effects of various soil covers on erosion and runoff for steep slopes have been made in several areas of high rainfall tropics. Vicente-Chandler (1953), working in Puerto Rico, reported that runoff from plots on a 40 per cent slope with an annual rainfall of 71 inches was more than ten times less when cane trash was left as a mulch than when it was burned. Molasses grass was also much more efficient than burned cane trash in erosion control. Smith and Abruna (1955), working with red clay latosols of 40 to 53 per cent slope in Puerto Rico, found that natural (bare) fallow soil lost an average of 26 inches of water and 253,000 pounds of soil per acre per year over a six year period, whereas plots with cultivated crops lost an average of 5.07 inches of water and 4,400 pounds of soil in the same period of time. When cane leaves were used for mulch instead of burned, soil loss, which was 15,240 pounds per acre per year, decreased to 1,370 pounds, though runoff remained the same. On red sandy loams with a 6.6 per cent slope in Tanganyika, Van Rensburg (1955) found that the average runoff from storms for eight seasons decreased from 31 per cent on plots with sorghum to 15.5 per cent on plots with narrow grass belts across the slope. Runoff was further decreased to 11.5 per cent when the top half of the plots were cultivated and grass was left on the lower half. The least runoff of 4.9 per cent occurred under a full grass cover. In an experiment by Suarez de Castro (1953) in Colombia, burned plots had only 44 to 48 per cent of the runoff of cut but unburned plots, though the soil losses on the unburned areas were from 76 to 89 per cent of the burned fields. In another experiment comparing erosion losses on bare soil,

pasture and coffee under an annual rainfall of 100 inches, Suarez de Castro and Rodriguez (1955a) reported that nutrient and soil losses were much greater than those observed for agricultural soils of temperate climates.

Literature on the effects of shifting cultivation on erosion is scarce and factual data is almost nonexistent. Freeman (1957) observed in Sarawak that when virgin forest was cultivated for one season only, erosion was slight. He suggested that erosion might become serious when land is farmed for two or more years in succession or when the cycle of cultivation becomes too short. Cater (1939) and Hardy (1942) described the accelerated erosion on the hillsides in Trinidad aggravated by the large increase in the amount of shifting cultivation. For Central America Cooke (1931) listed some of the factors which he considered caused the decline of the Maya Empire. They were: (1) erosion of the soil and the consequent scarcity of arable land, (2) silting of the lakes and the destruction of water transportation, and (3) diminution of the water supply during the dry season. However, Charter (1940), who did a soil survey of British Honduras, denies emphatically that large-scale erosion ever took place in areas occupied by the Maya.

THE POLOCHIC VALLEY OF GUATEMALA

The Polochic Valley is one of two main river systems which drain the eastern slope of the highly elevated Guatemalan uplands into the Caribbean Sea. It joins the northern Department of Alta Verapaz with Lake Izabal to the east. Lake Izabal is a large body of fresh water, 27 miles long and 12 miles wide, which is accessible by river boat from the seaport of Livingston. Throughout the river's length of 65 miles it twists and turns, dropping sharply from 4,000 feet to near sea level in the first quarter of its course. During the brief dry spell in March it is a pleasant, peaceful stream, providing water and transportation for the residents along its banks. During the summer rainy season, it becomes a savage giant, gouging and chewing away vast pieces of land, and recklessly spilling out of its bed onto the floodplain where it rapidly devours cornfields, laboriously cleared from the forest by patient farmers. Afterwards, it races on to Lake Izabal. There the turbulent waters are calmed and large beds of silt are deposited, rapidly expanding the swampy delta. The river is young and evidence of the dynamic state of its evolution is reflected in the rapidly changing landscape.

The topography of the area surrounding the Polochic Valley is exceptionally rough; very few people have scaled the peaks of the rugged Sierra de las Minas which forms the southern boundary of the valley and separates it from the larger valley of the Motagua River

to the south. The mountains north of the Polochic Valley are less rugged; and much coffee, as well as corn, is raised in this area. Since most of the corn is produced by shifting cultivation, the resulting effect on the landscape is a patchwork mosaic of vegetation, consisting of forests, cleared fields, and young second growth.

Some semipermanent agriculture is found in the valley bottom along the rich floodplain of the Polochic River. Pasture, corn, sugar cane and many other minor crops are grown almost continuously. Further up the slopes are the coffee farms, clinging precariously to the steep lands. Surrounding them on the poorer soils are the cornfields interspersed with forest and second growth.

The soils of the valley bottom consist of rich, deep alluvium, derived from limestone and shale. The soils of the steep foothills are more shallow, but in many cases are very fertile due to the ever-renewing influence of mild erosion. The hill soils clearly reflect the influence of parent material: soils overlying limestone at a very shallow depth are calcareous in nature while other soils are much more acid.

Geology

The heartland of the Department of Alta Verapaz in Guatemala is an elevated area of rugged karst topography which Stuart (1950) called the Meseta de Cobán. Near the southern end of this tableland lies the town of Tactic at an elevation of 4,854 feet. The Polochic River begins just east of Tactic and, after plunging sharply down a

steep-sided gorge, meanders along a flat valley floor which is more than 6 miles wide at its eastern end. The Polochic River at its western extremity separates two parallel mountain ranges which have an easterly trend--the Sierra de Pansal on the south and the Sierra de Xucaneb on the north. The Sierra de Xucaneb extends eastward into the Sierra Tzalamilá' which reaches elevations of about 6,500 feet. Facing it on the southern side of the valley is the large Sierra de las Minas, towering up to 9,000 feet.

The Sierra de Pansal consists of limestones of Permian age. These mountains were the result of folding and faulting along an east-west axis during the Pliocene orogeny. Much of the range was mapped by Roberts and Irving (1957) as Chochal limestone and dolomite which they assigned to the middle Permian. This formation is equivalent to Sapper's "Carbonkalk" which he (1937) had earlier classified as Carboniferous. In a few places the underlying Santa Rosa formation (early Permian) crops out, exposing strata of interbedded limestone, conglomerate, marl, shale and sandstone.

The lower slopes of the Sierra Tzalamilá' are composed of undifferentiated Pre-Cambrian metamorphic rocks such as schists, gneisses, phyllites, quartzites, and marbles. The range is topped by Chochal limestone which forms a characteristic, sharply-defined escarpment along the southern margin, which can easily be seen from the Polochic Valley below.

Climate

The climate of Alta Verapaz is determined primarily by the effect of the mountains on the trade winds and occasional northerlies. The "trades", coming from the northeast, bring much precipitation during the summer months. The mountain slopes facing north and east receive the greatest amount of rain, whereas those facing south and west are in the rain shadow and consequently are drier. During the winter months, occasional cold air masses move down from North America, bringing a few days of lowered temperatures and drizzly rains.

Since the Polochic Valley has an easterly trend and is protected on the north by the high Xucaneb and Tzalamilá ranges, the winter months are relatively dry, because here the northerlies can no longer produce much rain. During the summer months most of the rain is produced locally by fast-moving convectional storms which move up the valley from the east. The rains generally have a high intensity and are frequently accompanied by violent displays of lightning. The lower slopes of the mountains receive more rain than the valley floor, though the orographic effect diminishes on the upper slopes.

Almost the entire Polochic Valley has a rain-forest climate except for some of the smaller protected valleys and leeward slopes. Precipitation values in Table 1 are for stations in close proximity to areas sampled in this study. The data has been compiled from Sapper (1932) and from unpublished rainfall records collected by the Instituto Meteorológico de Guatemala through the cooperation of owners

TABLE 1

MONTHLY PRECIPITATION AND MAXIMUM-MINIMUM TEMPERATURES FOR VARIOUS STATIONS^a IN POLOCHIC VALLEY, ALTA VERAPAZ, GUATEMALA

Month	Precipitation				Temperature				
	Trece Aguas ^b	Seamay	Westfalia ^b	Cabañas	Mocca	Los Alpes	Cabañas	Mocca	Los Alpes
	1902-23 mm.	1955 mm.	1910-18 mm.	1953-55 mm.	1947-55 mm.	1947-55 mm.	1955 °C.	1939 °C.	1939 °C.
January	188	90	110	59	127	122	16-30	14-27	15-26
February	221	79	61	44	106	103	15-29	14-30	15-27
March	139	67	48	55	76	63	20-33	10-28	14-26
April	220	69	62	103	92	104	21-35	15-31	14-26
May	408	215	142	228	227	246	20-34	16-29	16-26
June	951	412	376	473	513	592	19-33	17-27	16-25
July	1063	538	469	467	589	628	20-32	16-27	16-27
August	823	435	388	390	441	472	21-34	16-28	16-27
September	674	298	235	326	461	498	21-34	16-26	18-27
October	492	696	162	256	493	432	19-32	14-25	18-27
November	267	284	108	175	230	207	19-30	13-24	13-23
December	161	145	92	65	117	160	15-31	14-26	14-23
Annual Average	5617	3326	2256	2641	3471	3627			

^aElevations in meters for the stations are as follows: Trece Aguas 725, Seamay 838, Westfalia 500, Cabañas 100, Mocca 1040, and Los Alpes 900.

^bData from Sapper (1932).

of the various farms. The geographical relationships of the stations may be seen on the map in Figure 1. All stations have an annual rainfall of more than two meters and as much as five meters falls in some areas. Months with less than 50 mm. precipitation are extremely rare. Large variations occur between stations because of the orographic effects of the mountainous topography. Trece Aguas has an average annual rainfall of 5,617 mm. whereas less than half that amount (2,256 mm.) falls on Westfalia.

According to Sapper (1932) the annual mean temperature at sea level is approximately 26 to 26.5° C. and the temperature lapse rate for Alta Verapaz is 0.61°C. Thus for each 100 meter rise in elevation the average annual temperature decreases by 0.61°C. At elevations higher than approximately 1,400 meters, occasional frosts are reported. The coldest months occur during winter. Data in Table 1 are unpublished values of maximum-minimum temperatures collected by the Hempsteads for three of their farms in the Polochic Valley. At sea level the difference between winter and summer minimum temperatures is approximately 6° C., but at higher elevations the variation is reduced.

Since the lowlands of the Polochic Valley have higher temperatures (and also less clouds and more sunshine) than the surrounding slopes, corn growth in the bottomlands is much faster than at higher elevations. As previously mentioned, two crops of corn may be harvested in the valley proper during a growing season, but at higher elevations twelve months may be needed for one crop of corn to mature. This is especially true in the mountains above Tactic.

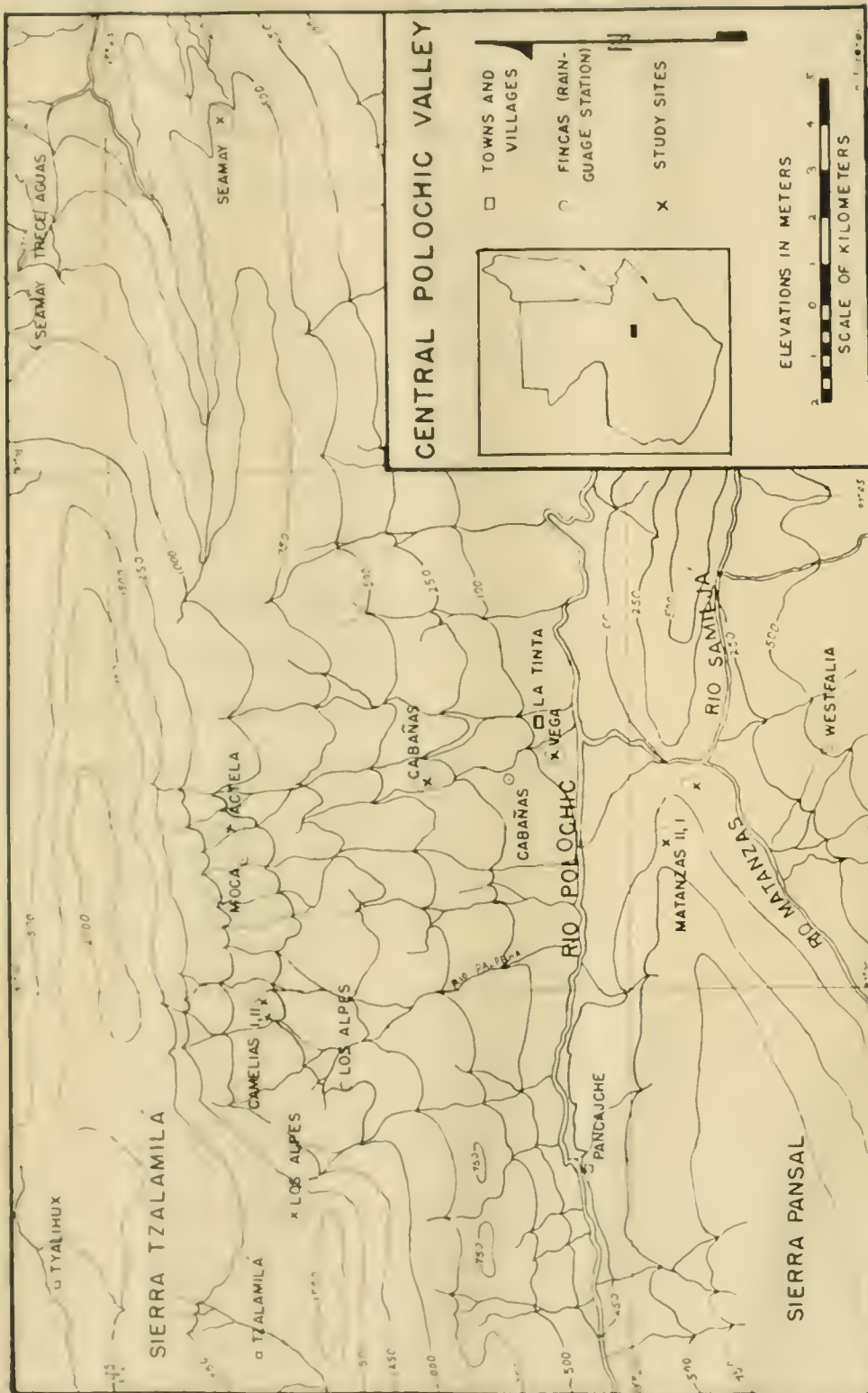


Fig. 1.--Map of Central Polochic Valley in Guatemala showing location of field sites and rain guage stations.

Vegetation

The dominant vegetation type of the Polochic Valley is the tropical rain forest, as one might predict from the climate. However, changes in topography and soils produce local modifications in the plant cover.

Stuart (1950) modified Sapper's original classification (1903) of the Alta Verapaz vegetation into five zones: (1) lower broadleaf forest, (2) lower savannas, (3) upper broadleaf forest, (4) upper pine forest, and (5) cloud forest. Of these, only the lower savanna zone is not properly found within the Polochic Valley.

Pine forest (Pinus caribea and P. oocarpa) occurs in scattered patches throughout the Polochic Valley, generally on the more sandy soils or on serpentine found near Lake Izabal. At one time pine may have been more widely distributed as Cook (1909) indicated:

In eastern Guatemala the secondary character of supposedly primeval forests is shown by the fact that pine roots are often found in the ground in districts from which living pines have been completely driven out by the more luxuriant tropical types of vegetation. The Indians dig up the pitchy roots of the extinct pines and use them for torches. Such roots are found in the alluvial bottom lands of the Polochic Valley, near Panzós, almost at sea level, and also in the coffee district to the north of Senahú at altitudes of about 3,000 feet and upward. Both localities are distant several miles from any living forest of pine.

Since no areas under pine were included in the present study, the discussion shall be restricted to the three broadleaf groups listed by Stuart.

The extent of the lower broadleaf forest coincides with the range of the Corozo or Cohune palm (Attalea cohune), which is restricted

to elevations below 800 meters. Mahogany (Swietenia macrophylla) and rubber (Castilleja elastica) are additional characteristic species. The corozo palm occupies a dominant position either because of its better adaptation within the climax formation, or because it is selectively protected by the inhabitants of the area who value it because of the high oil content in the seed and who protect it when they make their clearings in the forest. Dominance of the corozo palm has not been intensively studied, though Stevenson (1928) believed it was a climax formation. However, Hartlett (1936) believed it to be sub-climax, the climax being the mahogany-sapodilla forest. At present, large areas are now covered by almost pure stands of the palm. Diversity and number of species among the forest trees in this formation are probably the same as described by Record and Kuylen (1926) for the Motagua Valley, which runs parallel and adjacent to the Polochic Valley. They said:

. . . there are no pure stands of single species, but the trees which commonly rise above the others are less than twenty in number. Dr. H. N. Whitford, who visited the region in 1919, estimated that three-fifths of the stand was composed of five species, namely, tamarindo (Lialium divaricatum), naranjo (Terminalia obovata), masico (Brosimum terrabanum), zorra (Schizolobium parahybum), and ceiba (Ceiba pentandra).

The lower broadleaf forest extends up to the lower limits of intensive coffee cultivation and at one time was probably covered with rain forest. Shifting cultivation has considerably modified the vegetation and at present very little true virgin forest exists. The present-day vegetation has many deciduous components, except where

ground water is near the surface, for the dry season, though short, is quite severe. In areas of rocky limestone outcrops, the formation assumes a much more xeric appearance.

Undergrowth in the lower broadleaf forest is scant. One can usually walk among the trees unhindered by ground cover. A profusion of creepers and herbaceous plants usually indicates that the forest has been cleared recently. Epiphytes are plentiful though not as abundant as at higher elevations. Lianas, though not frequent, are well represented. The trees have the usual buttresses and smooth bark characteristic of rain forest trees.

The region of the upper broadleaf forest is commonly referred to as the "coffee zone." Since much of the better land is used for coffee, very little mature forest persists except for areas where it has been preserved along streams to protect the watershed. There doesn't appear to be a very distinct difference between the upper and lower broadleaf forests except for the absence in the upper zone of several ultratropical species as Attalea cohune, Swietenia macrophylla and Castilleja elastica. Record and Kuylen (1926), for the Motagua Valley, said: "The higher lowlands merge into the foothills and while the same species may be found, their relative abundance changes, and naranjo and tamarindo become more common. Still higher up, the characteristic tree is the Santa Maria (Calophyllum Calaba)."

The humid cloud forest is found in the subtropical zone. The lower boundary coincides with the upper limits of coffee-growing and the frost-free zone. This usually occurs above the 4,000 foot contour.

More virgin forest is found in this area since the land has little value for coffee and the growing season for corn is much longer than at lower elevations.

The general aspect of the cloud forest is one of dampness. Usually the trees are enveloped in a heavy fog or mist, since the moisture-laden winds, sweeping in from the ocean, are lifted and cooled by the mountains, condensing on the upper slopes. Since the air is saturated with moisture and evaporation is low, the vegetation is well adapted to an environment of high atmospheric humidity. Epiphytes abound in much greater amounts than at lower elevations. Orchids, bromeliads, mosses and hygrophilous ferns grow in profusion on the trees and fallen logs. Tree ferns are also very abundant. This area possesses one of the richest floras of Guatemala. Standley (1945) said important tree species were: Liquidambar styraciflua, Hedyosmum mexicanum, and Engelhardtia guatemalensis.

Vegetational successions after primary tropical rain forest has been cut have never been studied adequately. Richards (1952) in his classic book called this the most serious gap in our present knowledge of the tropical rain forest. He says:

Though many types of secondary vegetation derived from Tropical Rain Forest have been described, they have seldom been closely studied and very few systematic observations have been made on the successions of which they are stages. It is unfortunate that this should be so, because no aspect of the ecology of the Tropical Rain Forest is of greater practical value or promises results of more theoretical importance.

An investigation on forest regeneration after clearing might possibly provide answers to such questions as: (1) What are the various

successional stages from cleared field to climax rain forest? (2) What is the nature of competition in a tropical rain forest? (3) What are the processes involved in determining the great heterogeneity of species found in the climax rain forest?

Not enough time was available in the field to make more than limited observations of secondary successions following the abandonment of cultivated lands. Early plant species invading recent clearings in the Polochic Valley were caña brava (Gynerium sp.), bracken fern (Pteridium aquilinum) and Heliconia sp. It is felt that in the future a detailed successional study would yield much useful information on the rate of rejuvenation of soils after establishment of second growth and also on the competition among different forest species. The Polochic Valley would be ideal for such a study since shifting cultivation leaves a pattern of old forest, young second growth and cleared fields lying in close proximity. Thus a large variety of seed sources are available which provide plant material for colonizing old fields. In the following paragraphs the literature available from Central America has been used to indicate the information obtained so far which may show the sequence of events possibly taking place in the Polochic Valley.

Allen (1956), for Costa Rica, said:

A considerably greater number of species invade the hillside clearings than are found on the flat land which may reflect the better drainage conditions, or indicate an inherent preference for clay. Hillside clearings in particular seem to go through a long cycle, usually involving a succession of three or more distinct populations before something approximating the

original climax association can be re-established. A fairly typical, if somewhat simplified, succession might begin with a rapidly developing herbaceous cover, composed of Neurolaena and various Heliconias and Calatheas, followed for a few years by short-lived trees such as Ochroma lagopus, Muntingia calabura, and Trema micrantha. These tend to be gradually replaced by Goethalsia meiantha and Hydnopanax Morototoni, or an association of Schizolobium parahybum and Hieronyma tectissima, or nearly pure consociations of various species of Vochysia, or sometimes Brosimum utile. These last will probably reach the height of the general canopy, and persist for many years, being slowly invaded thereafter by other less specialized forest elements.

Stevenson (1928) gave typical species of the early stages of second growth in British Honduras as Ochroma bicolor, Belotia Campbellii, Heliocarpus Donnell-Smithii, Schizolobium parahybum, Cecropia mexicana, Bordia alliodora, Guazuma ulmifolia, Miconia spp., Inga spp., Caliba pentandra, and Trema sp. Hardy et al. (1935) add that the later stages of secondary forests include only isolated specimens of these species; the more recent secondary growths contain Cedrela mexicana and Brosimum alicastrum, which is typical of secondary forests on calcareous soils.

Species and rate of growth of secondary forests in northern Guatemala were given by Lundell (1937) as follows:

In southern Petén milpa clearings abandoned for about six years were overgrown with secondary forest which averaged about 10 meters in height. Some of the trees were as much as 20 cm. in diameter, but the majority were smaller. Commonest trees were Vitex gaumeri, Lonchocarpus guatemalensis, Bursera simaruba, Cecropia sp., and Cochlospermum vitifolium. Weedy herbs which characterize the growth in abandoned milpas for the first few years had been choked out by the forest vegetation. In a milpa which had been planted the

previous season, I collected three herbaceous weeds. Hyptis capitata, Eupatorium pycnocephalum, and Neurolaena lobata.

In Monte Chicbul in Central Petén a five-year secondary growth after milpa averaged about 8 meters in height. The dominant species was bitze (Inga punctata ?). However, Cecropia sp., Nectandra sp., Matayba oppositifolia, Casearia javitensis, and the tall shrubby Cordoncillo (Piper spp.) were all abundantly represented. The floor was entirely free of grasses and other weeds which typify the first phase after abandonment. These had been smothered by the taller rank secondary growth. Matayba oppositifolia and Casearia javitensis, dominant and subdominant respectively in the adjacent high forest, will be the important trees in this plot also when the succession again reaches the sub-climax stage.

Many rain forest trees grow very fast. Richards (1952) said Ceiba pentandra will grow 12 meters high in 3 years whereas Ochroma grows to a height of 24 meters and a girth of 2 to 3 meters in 15 to 20 years. Secondary forest in the Polochic Valley was observed to grow at a very rapid rate. Many trees in four year second growth reached a diameter of 6 inches and a height of 25 feet. The rate of growth varies widely depending on the soil.

The conclusions by Hardy et al. (1936) on the relationship between soil types and vegetation for south-central Trinidad have equal application elsewhere in the humid tropics and are included here since they hold true for the Polochic Valley. They summarized their discussion with the following remarks:

This brief review of the relationships between environmental conditions and the distribution of the different forest-types of south-central Trinidad indicates that the main factor deciding their occurrence is soil moisture, whose magnitude and availability depends, not only on total rainfall and topography, but also on the physical features of the soil-types that are represented

within the region. When these three factors operate in the same direction to confer a high water-supplying ability on the soil (heavy rainfall, flat or depressed topography, a suitable degree of permeability, conductance and retentivity for water in the soil), the wetter types of forest predominate. When they confer a low water-supplying ability on the soil (small rainfall, sloping topography, impermeable, non-conducting, non-retentive soil), a dry type of forest develops. Various intermediate types between these two extremes occur whenever the three factors act in opposite directions, or when their respective magnitudes diminish or increase disproportionately. All the observed variations in vegetation may be attributed to the interplay of these three factors. Soil-type appears to be significantly important mainly with respect to those physical features that decide its moisture relations. Its chemical properties and attributes appear to exert little or no influence, except in-so-far as they affect the behaviour of soil water. Among the chemical features, lime and magnesia contents and humus content alone appear to be important in this connection. Other chemical factors (nitrogen supply, phosphate content, potash content, etc.) seem to be quite subsidiary in deciding the broad distribution of vegetation types, although they may assume important roles when forest lands are utilized for the growing of commercial crops.

The People

The population of the Polochic Valley is very roughly estimated by the writer to be near 25,000. It is mainly comprised of three groups, namely, (1) indigenous inhabitants of Maya ancestry (by far the most numerous), (2) *ladinos* (mixed Indian and Spanish blood, rapidly increasing), and (3) the few owners of large coffee fincas (farms), sometimes of Caucasian ancestry. Although most land belongs to the last group, any member of the other two groups may also be property owners.

Two linguistic groups of Maya stock are present in the Polochic Valley--Kekchi and Pocono. The Kekchis are much more numerous. Kekchi women characteristically wear a white cotton blouse (huipil) which in some places is replaced by rayon of various colors, though the style remains the same. The Pocono women can be distinguished by a red turban and heavily embroidered red blouse.

Many ladinos have filtered into the Polochic Valley from the Guatemalan highlands in recent years, following the completion of a road in 1948 and improved malaria control. The term "ladino" is often used loosely in Guatemala to refer to anyone of mixed blood or to those who do not strictly adhere to the customs of their tribe. One informer said that a "ladino" is anyone wearing shoes. The ladinos are employed as skilled labor (truck drivers, overseers, etc.) on the coffee farms, or are self-employed in small businesses.

Owners of large tracts of land represent a very small minority of the population. Formerly many were Germans, but deportation of Nazi-sympathizers and expropriation of their lands during World War II decreased their numbers. Many of the German-owned fincas were nationalized and are now operated by the Guatemalan government.

Large Indian villages are few. Instead, the Kekchis live in widely scattered houses. The family is the basic unit and most settlements consist of one house only. Large families may occupy two or three neighboring houses. Occupation of houses is permanent--no large shifting of population occurs. A person may be born and die in the same house. However, an expanding population in the last few years (possibly

attributable to the introduction of modern medicines) has caused some population pressure and, consequently, some Indians have migrated to less crowded areas.

Land near the houses is used for growing a wide variety of dooryard crops. Some popular garden plants are: achiote, beans, cassava, chayote, corn, Job's-tears, pigeon peas, squash, sugar cane, sweet potatoes, taro and Xanthosoma. Cropped land further away from the houses is dominated by corn. Tree ownership, often found in the South Pacific, is not part of the Kekchi culture. When a house site is abandoned, the trees may be destroyed by the former occupant. Another cultural characteristic of Kekchi agriculture is that women almost never work in the fields; their chores are restricted to household and domestic duties.

Three main types of shifting cultivators are found in the Polochic Valley, namely, (1) landowners, (2) coffee finca workers occupying land in return for services, and (3) squatters. Indians who have ownership of the land they farm are few and are found in more isolated areas. Squatters may or may not have rights to other land in addition to that which is occupied by squatting.

The largest amount of land under shifting cultivation in the Polochic Valley is occupied by Indians who have part-time employment on the coffee fincas. This land is owned by the large fincas and in return for use of the land, the cultivator must work part-time. This type of cultivator may be divided into three groups--locally called "cclonos," "meseros," and "cuadrillas"--on the basis of the amount of

time spent working for the finca and the type of remuneration in return for their services.

The "colonos" work about half-time for the finca and receive no payment in return. Instead, they occupy enough finca land to satisfy their needs when used for shifting cultivation. Boundaries of assigned land are defined by usage and are well-known (the upper Polochic Valley has no land survey). The "colonos" are mostly concentrated in the lower rain forest zone but some occupy land in the coffee and upper cloud forest zones, though less land is available there. All sites studied in the present investigation were farmed by "colonos" with the exception of the highly fertile site, Vega. The available land which can be used for shifting cultivation is near saturation and the fincas discourage "colono" occupation.

The "meseros" reside in the coffee zone. They work the greater amount of time for the finca and in return receive small pay, rations (25 pounds of corn per week per couple), house, and a small piece of land for corn and garden crops. The "mesero" works six days per week for the finca but is allowed two weeks vacation for clearing land, one week for planting, nine days for weeding, and nine days for harvesting. In addition, he has five national holidays and three finca holidays per year.

"Cuadrillas" occupy finca-owned land in isolated areas, far removed from coffee production areas. They travel to the finca in large groups, when labor is most needed, and work a few weeks per year. The remainder of their time is spent farming land, assigned for their

use, with traditional shifting cultivation methods. Land occupied in this manner is mostly in the upper cloud forest or coffee zones. The type of farming used by the "cuadrillas" probably differs less from ancestral methods than the type used by "colonos" and "meseros."

The writer believes that food production by shifting cultivation in the Polochic Valley is a limiting factor now in population expansion there. If medical improvements continue to increase the population growth, more efficient methods of agriculture will be needed.

Shifting Cultivation

The shifting cultivation cycle in the Polochic Valley is relatively short and is typified by the use of a single cultigen--corn. The land is cropped for as little as one year, following clearing and burning of the forest, before abandonment to second growth. First year corn yields are reported to be about ten to twenty bushels per acre while yields for a second crop, if planted, are often reduced by one-half. Second growth is allowed to develop for an average of four years before it is cleared for another crop of corn. The average size of cleared fields varies from one to six acres, though much more land is occupied by second growth and old forest at any one time. Field size is governed by the fertility of the land, previous use of the area, type of fallow vegetation, and number of persons in the cultivator's household. Since the fields are usually small, several stages of shifting cultivation may join in an area of relatively uniform soil, which is a convenient situation for a study of the effects of shifting cultivation on soil properties and vegetation.

Usually, land which is selected for clearing supports a good stand of second growth or old forest. The nature of the vegetation is important for several reasons: rate of second growth rejuvenation and type of vegetational succession indicates inherent soil fertility; fast-growing, woody vegetation crowds out many of the more tenacious herbaceous weeds, requires less labor for clearing, and burns with a hot fire. In this respect, caña brava (Gynerium sp.) is one of the most desired types of second growth vegetation by the shifting cultivator.

Land to be cleared is usually marked off at the beginning of the dry season. The selection of a site by the shifting cultivator is usually limited to the confines of land owned by him or belonging to the large landowner for whom he may work. Usually clearings are located near the home, but some Kekchis use land that is three hours walking distance from their residence. Cook (1921) described one instance of Kekchis going sixty miles to farm and covering the distance on foot. In such cases, small huts are erected in the fields and the farmers live there while the crop is planted and harvested.

Once the site has been selected and the boundaries marked, the next task facing the indigenous farmer is that of felling and clearing the forest. Large trees are usually cut with an axe, leaving about one meter of exposed stump. The smaller trees are cleared with the machete. Much clearing is done in the Polochic Valley during the month of March at the height of the dry season. This allows the brush to dry out thoroughly for burning before the onset of the summer rains.

However, Steggerda (1941) found farmers of the drier Yucatan Peninsula clearing in the rainy season because, "The trees, full of moisture, are easier to cut and, covered with leaves, insure a better burning when dried." The farmers, when clearing forest, probably have a selective effect on the vegetation by preserving the more valuable trees.

Lundell (1937) found that when old forest was felled in northern Guatemala, the large valuable trees such as corozo and thatch palms, zapote, and ramon were spared. Firewood and usable lumber, in most cases, is carried from the field before burning.

The felled brush on cleared land is burned shortly before the first rains in April or May. This clearing when planted is called "milpa de fuego" (fire cornfield) in Spanish in contrast to the "milpa de verano" (dry season cornfield) which may be planted afterwards in part of the same field. During the time of burning the atmosphere over extensive areas becomes darkened with smoke, seriously limiting visibility and irritating the lungs and eyes. The burn must be well-timed for, if too early, weeds will sprout before enough rain falls to germinate the corn; if too late, new growth and wet wood seriously hamper an adequate fire.

The writer saw very little evidence in the Polochic Valley of fires escaping from the confines of clearings into the fire-resistant rain forest. All burned areas, with the exception of one, observed at the end of the dry season appeared to follow the straight lines of field boundaries. Nevertheless, several local residents were familiar with occasions when fires had escaped, causing great damage to the

adjacent forest. In the nearby region of Petén, where the annual rainfall is less than in the Polochic Valley, escaped fires are much more frequent (Lundell, 1937).

Great emphasis is placed by the natives on securing a hot, uniform fire. Thus, they want the brush well distributed over the land and as dry as conditions will permit. On the Pacific coast of Guatemala, if enough brush is not available for a good hot fire, combustible material may be brought in from adjoining pieces of land. Apparently, the beneficial effects of a good fire are threefold. First, seeds and vegetative material which could give rise to a large crop of weeds are partially eradicated as, no doubt, are some animal and insect pests. Second, soil structure is improved by a hot fire (Budowski, 1956; Burgy and Scott, 1952, 1953; Scott, 1956). Third, plant nutrients are converted into readily available soluble salts from the oxidation of organic matter.

Planting in the Polochic Valley commences immediately after the beginning of the rainy season. Throughout the Maya area of Central America and Mexico, corn is the main staple and is the crop commonly planted in forest clearings. Occasionally, other crops may be grown with the corn, especially when planted near houses. Use of a single cultigen, corn, simplifies the task of measuring effects of shifting cultivation on the soil. Cook (1921), one of the earliest men to work on the problem of shifting cultivation in Central America said: "The problem of tracing relations between agriculture and natural conditions in Central America is much simplified by the fact that one staple crop is grown over the whole area."

One characteristic of shifting cultivation in the Polochic Valley, as in most other areas, is that absolutely no tillage of the soil is involved. Seed is planted directly among the ashes and charred remnants of the felled forest. A long, pointed, wooden stick (coa in Spanish, aulep in Kekchi), the style of which probably hasn't changed in the last three thousand years, is used to make a shallow hole into which the seed is dropped. In the flat lowlands, where the soil is more compact, points of the digging stick are reinforced with steel, or are hardened by drying over a fire. The planter makes a hole with the stick while standing, and then drops five or six kernels of corn before closing the hole with his foot. The seeds are planted at intervals of approximately three to four feet.

The amount of weeding necessary during the crop season depends largely on the previous history of the field. Land recently cleared from high forest requires relatively little weeding; land cultivated for several years in succession has to be almost continually weeded throughout the growing season. Sometimes grasses become dominant in a field used continuously, though crop production ceases in most fields before this stage is reached. Where grass does appear, it is quickly eradicated when the field is abandoned by the farmer to second growth. Observations of the writer while in Central America lead to the conclusion that the importance of grasses as weeds in limiting crop production is less above 2,000 feet than at elevations near sea level.

One of the most important ways in which invasion by grasses limits crop production is through the accompanying increase in rodent

population. The deflected succession from forest to savanna by burning results in a habitat much more favorable for rodents. During the early years of a grassland, the rodent population undergoes a very accelerated growth. When grass is plentiful in cornfields, this effect is reflected in the large number of young corn plants either killed or injured from physical damage inflicted by rats and mice. After a grassland has been established for a few years, the number of rodents builds up rapidly to a peak and then declines as natural enemies appear on the scene.

The invasion by bracken fern (Pteridium aquilinum) in shifting cultivation lands is a more important problem than grass at elevations above 2,000 feet. Bracken may interrupt the normal vegetational succession and, once established, reduces the usefulness of the land for corn. Shifting cultivators and finca owners try to rehabilitate such areas by encouraging other types of vegetation. Bracken may have some effect on soil conditions but the actual mechanism is unknown by the writer.

Weeds are generally cut close to the soil with a machete. Morley (1956) blamed the machete for the large number of weeds in Yucatan cornfields. He hypothesized that before the machete was introduced, plants were pulled by hand, and scattering of seeds was less. Nowadays, because weed competition is more severe than formerly, he reasoned, fields remain in production a shorter period of time.

Hoes are also used for weeding in the Polochic Valley, though much less than machetes. The hoe is employed strictly for cutting

weeds above the soil surface and, unlike drier areas of Guatemala, the soil is never disturbed. The natives hoe more frequently during the dry season than in the rainy season. It is quite possible that hoeing accelerates the process of erosion in high rainfall climates and for this reason is not more intensively used in the Polochic Valley.

The Kekchis never use draft animals and have not incorporated large livestock holdings into their agricultural system. Furthermore, the steep topography and rocky land discourages the use of plows. On similar land elsewhere in Central America oxen have been used to pull wooden plows but, no doubt, this hastens erosion of the soil. In some of the more fertile floodplain soils of the Polochic Valley, where permanent agriculture is practiced, crop production has been maintained almost continuously through the use of heavy machinery to till the soil. However, these soils have a high inherent fertility and, without cultivation, weeds would be the main limiting factor to a permanent agriculture.

Cornstalk bending or doubling by the farmer, common throughout the Maya area, is not practiced in the Polochic Valley. In other areas the farmer believes that birds find it more difficult to eat corn from an inverted ear and that, otherwise, rain water collects beneath the husk and promotes mold. The fact that cornstalks are almost never bent in the Polochic Valley might invalidate the rain water hypothesis, for the climate is certainly wet. However, the native corn husks are approximately three times thicker and much tougher than introduced varieties. Corn grown from imported seed is

much more susceptible to mildew during the ripening stage. Another advantage of the local thick-husked corn is protection against weevils, possibly the most important crop pest.

Harvested corn is often stored in the farmer's house above the cooking fire where it is kept dry. Smoke from the fire probably discourages depredations by weevils. Many times corn may be left unharvested for a long period of time in the field.

After corn is harvested in the lowland areas, a second crop (milpa de verano) may be planted immediately in part of the same field. Or, the farmer may clear a second field to take advantage of the long growing season. At higher altitudes, where the corn takes longer to mature because the average temperatures are lower, only one crop is harvested each year. In the mountains above Tactic one crop of corn may take more than a year to reach maturity.

The same field is rarely ever planted more than two years in succession. The period of fallow, during which time second growth covers the land, lasts from three to four years. As one proceeds northward through Petén and Yucatán, the length of fallow increases as the country becomes progressively drier.

The shifting cultivation employed now by the natives of northern Central America and southern Mexico is essentially the same as used by the Mayas 2,000 years ago. The Maya Empire subsequently declined, and many authors, foremost among which was Morley (1956), have suggested that the decline was a result of the failure of shifting cultivation to withstand the pressures of an increasing population. They hypothesized

that as the population increased, the time that land could be left under forest fallow decreased, and eventually the land became unproductive. More recent studies by other authors, of which Thompson's (1954) is one, have suggested that the Maya Empire disintegrated when the peasant class, oppressed by the burden of supporting an overlarge hierarchy finally revolted. The large number of broken monuments at some of the major ceremonial centers (Tikal and Uaxactun) appear to support this theory. Supposedly, the large agricultural areas of Petén and Yucatán gradually reverted to forest after the revolt, since a high form of civilization and organization was needed to successfully farm rain forest land in a humid tropical climate.

The answer to the above riddle has far-reaching significance today. Now that we are once again trying to utilize large rain forest areas for agricultural purposes, important questions arise. Can humid tropical lands on old soils be farmed successfully under any system? If a failure of agriculture caused the decline of the Mayas, what were the major limiting factors--soils, weeds, or pests? If the Maya Empire disintegrated as a result of a peasant revolt, why cannot the same lands be made productive today with our modern technology and more advanced civilization? The ecological basis of shifting cultivation must be studied before changes in the system can be considered.

EXPERIMENTAL PROCEDURE

Description of Sites

Shifting cultivation fields in the Polochic Valley were selected for study to represent as wide a range of climatic and soil conditions as were available in a limited area. The area chosen for the present investigation was midway between the ends of the Polochic Valley near the town of La Tinta. Sites were sampled from the valley bottom, near sea level, to an elevation of approximately 5,000 feet on Sierra Tzalamilá. The sites included the major geological formations, annual rainfall values varying from 2 meters to more than 4 meters, and very acid soils with a pH near 4.0 to soils with a pH higher than 7.

Samples of soil for chemical and physical analyses were collected from thirty fields in eight sites within an area of approximately one hundred square miles. At least two stages of shifting cultivation adjoined in each site. The time of sampling was during the middle of the cropping season. One field with an apparent high yield potential in the floodplain of the Polochic River was sampled as a reference. Site locations are shown in Figure 1 and descriptions are given in Table 2. More detailed descriptions of the mode of access, soils, stages of shifting cultivation, and other factors are given in the following paragraphs.

The Los Alpes site is on the north side of Los Alpes-Tzalamilá trail approximately one and one-half hours walking time from Los Alpes,

TABLE 2

FEATURES OF POLOCHIC VALLEY SITES INVESTIGATED IN SHIFTING
CULTIVATION STUDIES

Site	Longitude and Latitude ^a		Elev. m.	Prec. mm.	Temp. ^b °C.	Slope Percent	Erosion	Geology	Stages of Shifting Cultivation
Los Alpes	90°02'08"W. 15°23'11"N.		1720	3627	15.5	55	Negligible	Permian lime- stones	Old forest Corn after 5- year forest 2-year forest 5-year forest
Seamay	89°51'30"W. 15°23'43"N.		500	3326	23.0	25	Some gully	Pre-Cam- brian red schists	Old forest Corn after 3- year forest 2-year forest
Matanzas I	89°58'03"W. 15°19'12"N.		270	2256	24.2	80	Some sheet	Permian lime- stones	Old forest Corn after 4- year forest 2-year forest 1-year forest 1-year grass
Matanzas II	89°58'35"W. 15°19'34"N.		400	2256	23.6	5	None	Permian lime- stones	Old forest Corn after 5- year forest 2-year forest 5-year forest
Actelá	89°58'19"W. 15°23'43"N.		910	3471	20.4	95	Some sheet	Pre-Cam- brian metamorphic, phyllites	Old forest Corn after 6- year forest 4-year forest

TABLE 2--Continued

Site	Longitude and Latitude ^a	Elev. m.	Prec. ^b mm.	Temp. ^c °C.	Slope Per cent	Erosion	Geology	Stages of Shifting Cultivation
Camelias I	90°00'16"W. 15°23'22"N.	950	3627+	20.2	15	None	Pre-Cambrian metamorphic Pre-Cambrian phyllites	Old forest Corn after old forest Old forest Corn after old forest
Camelias II	90°00'03"W. 15°23'27"N.	975	3627+	20.1	25	None		
Vega	89°57'47"W. 15°20'32"N.	100	2641	25.4	2	None	Recent alluvial sediments	Continuous cultivation
Cabañas	89°58'46"W. 15°22'40"N.	295	2641	24.2	25	Very little sheet	Pre-Cambrian schists	Corn after 4- year forest Corn after 4- year forest 1-year forest 4-year forest

^aAll geographical coordinates are from: K. Sapper. 1902. Hohenschichtenkarte der Alta Verapaz (Republik Guatemala) 1:200,000. Die Alta Verapaz. Mittheilungen der Geogr. Gesellschaft in Hamburg XVII Karte 3. L. Friederichsen and Co., Hamburg. The same coordinates are found in Amer. Geog. Soc. Map of Hispanic America 1:1,000,000, Tegucigalpa sheet (1952) and Ciudad Guatemala sheet (1935).

^bAnnual precipitation value is for station nearest site.

^cTemperature calculated from sea level (26°C. annual mean temp.) assuming a temperature lapse rate of 0.61°C. per 100 meters.

and one-half km. south of the pass near La Tinta, A.V. Soils consist of 20 cm. of a friable, dark reddish brown clay loam with good crumb structure overlying a yellowish brown, sticky plastic clay with weak blocky structure. Organic matter accumulation is great because average temperatures are low throughout the year. In some places leaf mold is 25 cm. deep. Corn matures in eight or nine months because temperatures are low. Slight nitrogen and phosphorus deficiency symptoms were apparent on young corn plants. Tree roots were very highly concentrated in the top layer of organic matter; corn roots in cleared fields appear to feed deeper in the soil.

Fields at Seamay are adjacent to the west side of Seamay-Rosario road 17.0 km. from Seamay, A.V. Surface soils are friable brown clays with good crumb structure overlying sticky plastic, reddish yellow clays at 20 cm. The top soil has been mixed in many places by leaf-cutting ants. Some nitrogen and phosphorus deficiency symptoms were apparent on the corn plants.

Matanzas I is adjacent to the west side of La Tinta-Westfalia trail, approximately 500 m. west of the confluence of the Panimá (locally called Matanzas) and Samiljá rivers, and approximately 300 m. north of bridge across the Panima river. Soils are friable, dark reddish brown loams with well-developed crumb structure overlying a sticky, yellowish red clay at a depth of 20 cm. The soil profile appears truncated in some places. Decomposing limestone is found at depths of 30 cm. and many limestone outcroppings are present. Some leaf-cutting ants had killed a large part of the broadleafed vegetation in the two year old second growth.

Fields of Matanzas II are one-half hour walking distance west of La Tinta-Westfalia trail approximately midway between Panimá and Polochic rivers. Five cm. of dark reddish brown clays with crumb structure overlie brown clays with weakly blocky structure. Limestone outcroppings occur throughout the area. Some phosphorus deficiency symptoms were apparent on the corn plants, though otherwise the plants appeared quite healthy.

Actelá fields are 100 m. north of Mocca-Actelá trail and adjoin the northeast side of the first stream (Tamponá) east of Ermita San Miguel, near La Tinta, A.V. Dark grey brown sandy loams with good crumb structure overlie yellowish brown loams at a depth of 20 cm. Much gravel is distributed throughout the soil profiles. Corn plants near the forest margin appeared highly deficient in nitrogen, had thin stalks and lodged easily.

The site of Camelias I borders the south side of Mocca-Los Alpes trail at the first bend east of the largest river (Palpehá), approximately midway between the two farms. Dark red brown loams with strongly developed crumb structure overlie yellowish brown clay loams and clays at a depth of 20 cm. Growth of corn plants was extremely poor. The corn plants had almost no roots, a high incidence of lodging, and were extremely brittle. Some eighteen inch plants had produced ears, though the yield of the field was almost nil.

Fields of Camelias II border the south side of Mocca-Los Alpes trail by a spring in a cave, four km. from Mocca and 500 m. east of Camelias I. Soils are 5 cm. of dark brown loam overlying yellowish

brown clay loams. A strongly developed crumb structure exists throughout the rooting zone. Most corn plants grew less than eighteen inches and yields were exceptionally poor.

The site of Vega is approximately 300 m. southwest of La Tinta airport in the floodplain of the Polochic River. Friable, brown clay loams overlie sticky yellowish red clays at 30 cm. depth. Soil is very fertile, has good physical characteristics, and supported one of the best stands of corn (ten feet tall) seen by the writer in Guatemala. This soil has been in cultivation for a number of years using modern agricultural practices and machinery, though no fertilizers are applied. Corn in the tasseling stage at time of sampling appeared to have a yield potential of approximately sixty bushels per acre. Occasionally the land has been rotated with pasture or cover crops. The area was sampled as a reference, since apparently soil conditions were favorable for optimum corn growth.

The site of Cabañas I is on the west side of the Mocca-Cabañas road, 2.2 km. from Cabañas near La Tinta, A.V. Five cm. of dark reddish brown clays with good crumb structure overlie yellowish red clays with weak blocky structure. The soil profiles appear somewhat truncated. Many corn plants failed at tasseling stage though yield was approximately fifteen bushels per acre. Some of the brush was removed for firewood when the field was cleared. Results from this site were not included in the discussion on effects of shifting cultivation on soil properties, since no old forest was nearby for comparison and none of the fields included two year second growth. However, the analyses

have been used in the sections characterizing the general features of Polochic Valley soils.

Methods

Sampling procedure

Each stage of shifting cultivation at each site was sampled at ten random points during the middle of the cropping season, 1956. Pits were dug and samples were collected from depths of 0-5 cm., 5-20 cm. and 20-40 cm. by cutting into the soil profile with a large knife. All depths were measured from the soil surface which included forest litter in some cases. The thirty samples from each stage were composited into single samples by depths and placed into cloth bags. Thus, for each single sample analyzed from each plot, ten individual soil samples were taken, bulked in the field, and well mixed before subsampling in the laboratory. Two of the ten pits in each field were sampled in the 5- to 20-cm. zone with a 5 x 3.5 cm. cylinder for bulk density. The air-dried soil samples were shipped to the University of Florida for analysis. All samples with the exception of those for biological studies were fumigated with methyl bromide upon arrival in the United States.

Chemical and physical analyses

The soil was passed through a 2 mm. aluminum sieve and placed in ice cream cartons; pebbles were retained for geological characterization. Total nitrogen was determined by the A.O.A.C. (1955) Kjeldahl method with the modification that ammonia was distilled into a 4 per cent

boric acid solution and titrated with standard hydrochloric acid using a mixed indicator of bromcresol green and methyl red. Carbon was analyzed by the wet combustion method of Walkley-Black as modified by Walkley (1947).

Duplicate soil samples of 25 gm. were extracted with neutral normal ammonium acetate according to the method of Peech et al. (1947) and, after the solution was evaporated to dryness and organic matter was destroyed at 350° C. in a muffle furnace, the salts were taken up in two normal hydrochloric acid. The procedure described by Black (1955) was used to determine exchange capacity by distilling ammonia from the soil sample into a 4 per cent solution of boric acid and titrating with standard hydrochloric acid and a mixed indicator of bromcresol green and methyl red. Exchangeable potassium and sodium were determined in the hydrochloric acid solution with a Beckman Model B flame spectrophotometer with acetylene-oxygen burner assembly. Potassium was measured at a wavelength of 768 mμ and sodium at 589 mμ. The versenate method of Cheng and Bray (1951) was used for determining exchangeable calcium and magnesium in the hydrochloric acid solution after first neutralizing with potassium hydroxide.

Distilled water was added to the soil samples on a 2:1 volume basis (100 ml. water, 50 ml. soil) and, after twelve hours, the pH of the suspension was measured with a thin glass electrode. One ml. of one molar calcium chloride was then added to each sample and the pH of the soil in the 0.01 molar salt solution was measured after one-half hour (Schofield and Taylor, 1955). Exchangeable aluminum was extracted

from 10 gm soil samples with 100 ml. of normal potassium chloride and analyzed by the method of Coleman et al. (1959).

Acid-soluble and adsorbed phosphorus, extracted by the method of Bray and Kurtz (1945), was determined colorimetrically by the procedure of Truog (1930). Zinc and manganese were extracted with tenth normal hydrochloric acid and determined by Dr. H. L. Barrows using his polarographic procedure (Barrows, 1959; Barrows et al. (1956).

Soil samples were prepared for X-ray diffraction by the method of Kunze and Rich (1959) after organic matter was removed with ten per cent hydrogen peroxide and the clay had been separated after dispersion with 1 ml. of molar Na_2EDTA . X-ray diffraction patterns were obtained by copper radiation with nickel filter ($\text{CuK}\alpha$ according to specifications set forth by Fiskell et al. (1958), with the exception that 10 ma. current was used instead of 15 ma.

Biological analyses

It was decided to obtain an estimate of the microbiological activities of some representative soils within the Polochic Valley, since many of the results from the chemical and physical analyses of soils under shifting cultivation appeared to implicate soil biological factors. Samples for this study were collected in polyethylene bags by Mr. C. Hempstead in November, 1957, and shipped by air in moist condition to the University of Florida. The soils entered the United States without fumigation. Total time en route was two weeks.

The samples were collected from each of four fields--forest, second growth and two corn fields at depths of 0-15 cm. Samples from

cleared fields were collected near corn plants so as to include as many roots as possible for analysis of nematodes affecting crop production. The sites used for this study were Vega, Cabañas and one new site, Cabañas II. This last site was located 100 meters south of the farm buildings at Finca Cabañas on top of a limestone bluff immediately west of the main road. Vegetation was forest, though somewhat more xeric than the other sites. The soil was a very shallow clay loam overlying limestone at a depth of 20 cm. The site in Vega was near the site previously sampled for laboratory analyses, and produced crops continuously. Corn plants were twelve days old at time of sampling. Two fields were sampled at Cabañas, namely, one planted in corn the preceding season, and another in two-year-old second growth. These fields were identical to the fields previously sampled for chemical and physical analyses.

The rate of release of nitrate from soil organic nitrogen was measured on the samples in triplicate by the method of Stanford and Hanway (1955). Nematodes were separated and identified by Dr. W. H. Thames¹ using the technique of Christie and Perry (1951). Population counts of soil micro-organisms were made also on the samples by Thames. Rose bengal agar (Smith and Dawson, 1944) was used for plating fungi, and soil extract agar (Allen, 1949) for bacteria and streptomyces. Plating dilution for fungi was 1:1,000 and for bacteria and streptomyces,

¹Dr. W. H. Thames, Jr., Associate Professor of Soil Microbiology, Texas A. and M., College Station, Texas; formerly Interim Instructor in Soil Microbiology, University of Florida, Gainesville.

1:100,000. Subsequently the samples were submitted to Dr. W. R. Carroll¹ for isolation of organisms producing antibiotics. Special precautions were taken to treat all wash water, wastes, and apparatus used in the study with formalin. Soil samples were finally sterilized in an autoclave after the investigation.

¹Dr. W. R. Carroll, Professor, Department of Bacteriology, University of Florida, Gainesville.

RESULTS AND DISCUSSION

The results of laboratory analysis of soil properties at seven sites and under three stages of shifting cultivation--old forest, cleared land, and two-year second growth--in the Polochic Valley are shown under appropriate headings.

Chemical and Mineralogical Soil Factors

Clay minerals

The X-ray diffraction patterns for the clay fraction ($< 2 \mu$) of the 20 to 40 cm. horizons of Polochic Valley soils are shown in Figures 2 and 3. Interpretations of clay minerals from the patterns for each site are shown in Table 3. The clay minerals of most of the Polochic Valley soils are highly complicated. Dominant clay mineral types in most cases are three-layered with some interstratification. Seamay soils, however, are dominated by kaolinite.

The soils with the best crystallized clay minerals have the highest and sharpest X-ray diffraction peaks (Vega and Matanzas I and II). These soils are probably relatively younger than soils having more diffuse X-ray diffraction peaks (Los Alpes, Camelias I and II, Actalá). As will be shown in later sections, youthfulness of the soils, Vega, Matanzas I, and II, is also indicated by their high base status. The older soils, with degraded clay minerals, might be expected to have a higher fixation capacity for potassium than younger soils.

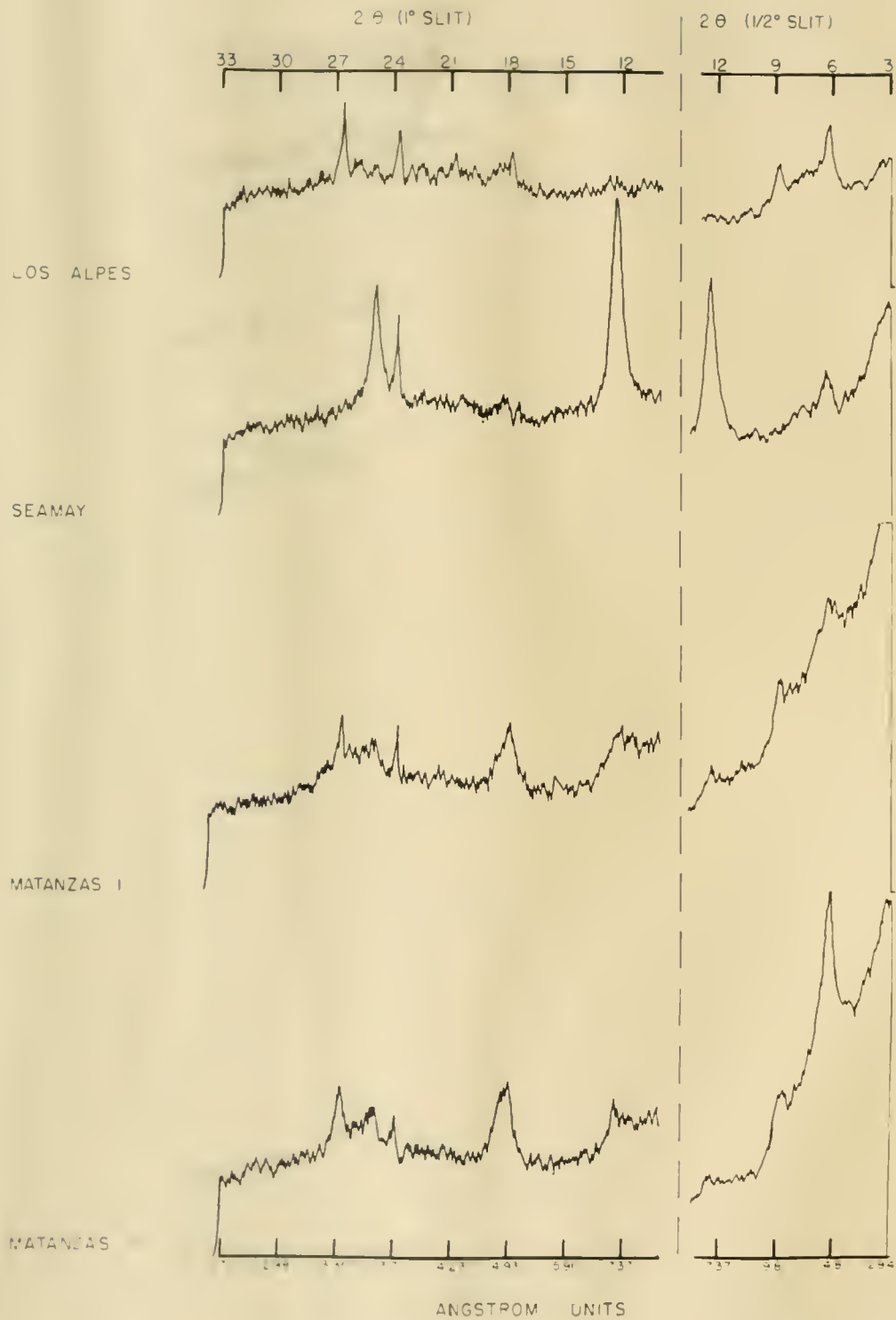


Fig. 2.--X-ray diffraction patterns for the clay fraction from four shifting cultivation sites in the Polochic Valley.

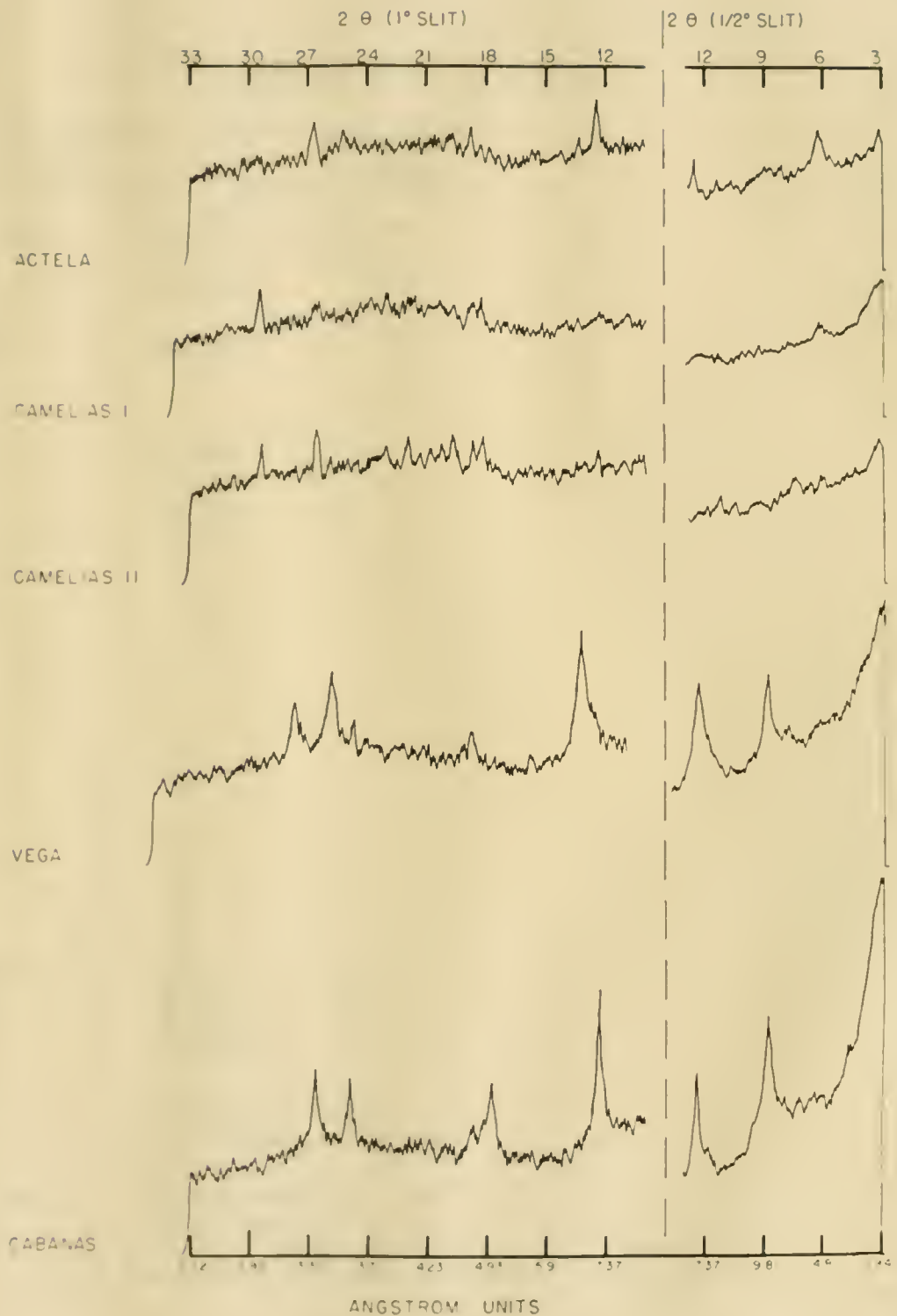


Fig. 3.--X-ray diffraction patterns for the clay fraction from five shifting cultivation sites in the Polochic Valley.

TABLE 3

CLAY MINERALS OF POLOCHIC VALLEY SOILS INTERPRETED
FROM X-RAY DIFFRACTION PATTERNS

Location	Dominant Clay Minerals	Accessory Clay Minerals
Los Alpes	Vermiculite, illite, interstratified three-layer silicates	
Seamay	Kaolinite	Vermiculite and interstratified three-layer silicates
Matanzas I	Well-crystallized, interstratified three-layer silicates, vermiculite and illite	
Matanzas II	Vermiculite, interstratified three-layer silicates	
Actelá	Well-weathered, highly degraded vermiculite, interstratified three-layer silicates	
Camelias I	Well-weathered, highly degraded vermiculite, interstratified three-layer silicates	Colloidal quartz
Camelias II	Well-weathered, highly degraded vermiculite, interstratified three-layer silicates	Colloidal quartz
Vega	Interstratified three-layer silicates and illite	Kaolinite
Cabañas	Interstratified three-layer silicates and illite	Kaolinite

The three-layer silicates found in the Polochic Valley soils on limestone appear to support Lawton's (1955) and Millot's (quoted by Grim, 1953) contention that sediments of marine origin which have not been highly weathered usually contain high amounts of these clay minerals. However, more recently, Weaver (1958) states: "there is no consistent coincidence between specific clay minerals and specific depositional environments."

Nitrogen and organic matter

The soils under shifting cultivation in the Polochic Valley are essentially forest soils and contain relatively high amounts of organic matter and nitrogen, especially in the surface layers (Table 4). Typical of forest soils, the organic matter content decreases sharply with depth.

Nitrogen content of the topsoil is almost invariably lowered when forest is cleared in the Polochic Valley. However, the losses are not nearly as great as one would expect and the average for seven sites in Table 4 falls from 1.13 per cent nitrogen to the top 5 cm. of old forest soils to 0.82 per cent for recently cleared land. The effects of clearing are noticeable throughout the depth of sampling as reflected by a corresponding drop in the 5 to 20 cm. and 20 to 40 cm. zones. These results substantiate similar investigations elsewhere (Coulter, 1950; Luthie et al., 1936; Giddens et al., 1957; Nye, 1958; Piquier, 1953). Organic matter losses after forest removal can probably be attributed to: (1) effects of burning, (2) reduction in

TABLE 4

NITROGEN AND ORGANIC MATTER CONTENTS OF POLOCHIC VALLEY
SOILS UNDER THREE STAGES OF SHIFTING CULTIVATION

Location	Depth	Forest			Cleared Land			2-year Second Growth		
		N	O.M.	C:N	N	O.M.	C:N	N	O.M.	C:N
	cm.	Per- cent	Per- cent		Per- cent	Per- cent		Per- cent	Per- cent	
Los Alpes	0-5	1.68	63.0	21.8	1.36	44.5	19.0	1.61	58.2	20.9
	5-20	0.41	18.5	26.0	0.49	14.4	17.1	0.31	8.8	16.3
	20-40	0.19	4.6	14.0	0.20	4.2	12.4	0.21	4.0	11.2
Seamay	0-5	0.42	10.9	15.3	0.37	7.3	11.6	0.31	7.3	13.8
	5-20	0.35	7.3	12.3	0.25	5.3	12.6	0.27	5.2	11.1
	20-40	0.20	3.9	11.6	0.17	3.6	12.4	0.15	3.0	11.5
Matanzas I	0-5	0.82	17.4	12.3	0.63	9.7	8.9	0.48	10.6	12.7
	5-20	0.60	9.9	9.6	0.37	6.3	9.9	0.25	4.4	10.2
	20-40	0.28	4.3	8.9	0.26	3.6	8.0	0.17	2.3	8.0
Matanzas II	0-5	1.19	29.3	14.3	0.62	13.0	12.3	0.63	14.8	13.5
	5-20	0.59	10.0	9.9	0.31	7.0	13.1	0.44	6.9	9.1
	20-40	0.26	4.2	9.2	0.13	2.1	9.3	0.25	2.9	6.8
Actelá	0-5	0.78	20.8	15.6	0.61	12.7	12.1	-	-	-
	5-20	0.44	12.2	16.2	0.42	10.9	15.0	-	-	-
	20-40	0.40	8.4	12.2	0.23	4.6	11.6	-	-	-
Camelias I	0-5	1.57	41.6	15.4	1.10	26.3	13.9	-	-	-
	5-20	0.65	17.2	15.5	0.51	13.5	15.4	-	-	-
	20-40	0.45	10.0	13.0	0.32	6.9	12.4	-	-	-
Camelias II	0-5	1.47	35.7	14.1	1.03	25.1	14.2	-	-	-
	5-20	0.69	17.8	15.0	0.66	14.7	12.8	-	-	-
	20-40	0.38	9.5	14.1	0.37	8.0	12.7	-	-	-
Average of First Four Fields	0-5	1.03	30.2	15.9	0.74	18.6	13.0	0.76	22.7	15.2
	5-20	0.49	11.4	14.5	0.35	8.3	13.2	0.32	6.3	11.7
	20-40	0.23	4.3	10.9	0.19	3.4	10.5	0.19	3.1	9.4
Average of All Fields	0-5	1.13	31.2	15.5	0.82	19.8	13.1	-	-	-
	5-20	0.53	13.3	14.9	0.43	10.3	13.7	-	-	-
	20-40	0.31	6.4	11.9	0.24	4.7	11.3	-	-	-

rate of litter replenishment, and (3) removal of shade (causing higher soil temperatures). Establishment of young second growth on cleared land restores some organic matter in the topsoil without materially altering the total nitrogen content because the newly added material has a high C:N ratio.

Values for the C:N ratios of shifting cultivation soils in the Polochic Valley are also given in Table 4. Los Alpes is the only site that has C:N ratios in excess of 16.5, and there the ratio does not exceed 19 for the cleared field. It can be seen from the discussion in the literature review that these C:N ratios should be low enough for good mineralization of nitrogen in the soil organic matter.

Clearing the forest by fire reduces the C:N ratio of the soil surface layer. No doubt, burning in this instance is beneficial. Otherwise, the freshly cut vegetation would probably immobilize much of the nitrogen supply available to the young growing crop. If the land were kept cleared for a long period of time, the C:N ratio might be reduced still further. The soil C:N ratio rises under second growth with the addition of fresh litter with a high C:N ratio.

The average nitrogen content for the topsoil of seven forest fields is 1.13 per cent (Table 4). This value may appear to be very high when compared with temperate climate soils, though not excessively so when compared with other areas of the very humid tropics. Values of the same magnitude have been reported from such places as Hawaii, British Honduras, Costa Rica, Colombia and Puerto Rico (see literature review). The principal reason for high organic matter levels in these

areas is probably the fast annual rate of biological production, uninterrupted by frosts or severe dry spells. Once production is reduced by removal of vegetation, soil organic matter levels generally decline.

Comparisons between soil organic matter contents and ratios of estimated rainfall to temperature are shown in Table 5 for each site in the Polochic Valley. The soil organic matter values reflect the influence of climate, generally increasing with increasing rainfall and decreasing temperature. Schaufelberger (1956) related the ratio of mean annual precipitation to mean annual temperature with organic matter for Colombian soils and suggested that soils with a ratio of 100 to 160 would contain 5 to 10 per cent humus, and soils above 160 would contain 10 to 20 per cent humus. The above data for Polochic Valley soils roughly approximate Colombian soils in this respect.

Figure 4 shows the relationship of C:N ratios to rainfall and temperature (elevation) for Polochic Valley soils. Data from the 20 to 40 cm. horizon were chosen since this zone is probably least affected by vegetative cover. C:N values are generally greater at higher elevations (where precipitation/temperature ratios are higher) than near sea level. C:N values are all below 11 when precipitation/temperature ratios are lower than 110, and entirely above 11 when ratios are higher than 140. Figure 5 shows the relationship between C:N ratios and topsoil organic matter for the Polochic Valley. As might be predicted, the soils with the most organic matter also have

TABLE 5

RELATIONSHIP BETWEEN CLIMATE AND ORGANIC MATTER CONTENTS
OF THE 5-20 CM. HORIZON OF SHIFTING CULTIVATION FIELDS
IN THE POLOCHIC VALLEY, GUATEMALA

Station	Prec. ^a	Temp. ^b	Prec. Temp.	Organic Matter		
				Forest	Cleared	2nd Growth
	mm.	°C.		Per cent	Per cent	Per cent
Matanzas I	2256	24.2	93	6.3	9.9	4.4
Matanzas II	2256	23.6	96	7.0	10.0	6.9
Seamay	3326	23.0	144	5.3	5.2	7.3
Actelá	3471	20.4	170	10.9	12.2	-
Camelias I	3027	20.2	179	13.5	17.2	-
Camelias II	3627	20.1	180	14.7	17.8	-
Los Alpes	3627	15.5	234	14.4	8.8	18.5

^aPrecipitation value is for station nearest site.

^bTemperature calculated from sea level (26° C. annual mean temp.) assuming a temperature lapse rate of 0.61° C. per 100 meters.

the highest C:N ratio, indicating the relatively undecomposed state of forest debris in such soils.

Cation exchange capacity, total exchangeable
bases and base saturation

The exchange capacities of Polochic Valley soils are high, due in large measure to their high contents of organic matter (Figure 6). The average cation exchange capacity for the topsoils under forest from seven locations is 88 me. per 100 g. (Table 6). The exceptionally large value of 187 me. per 100 g. for the topsoil under forest in Los Alpes corresponds to the high value of 63 per cent organic matter for the surface soil there. In almost all soils the exchange capacity decreases with depth which corresponds to a decrease in soil humus.

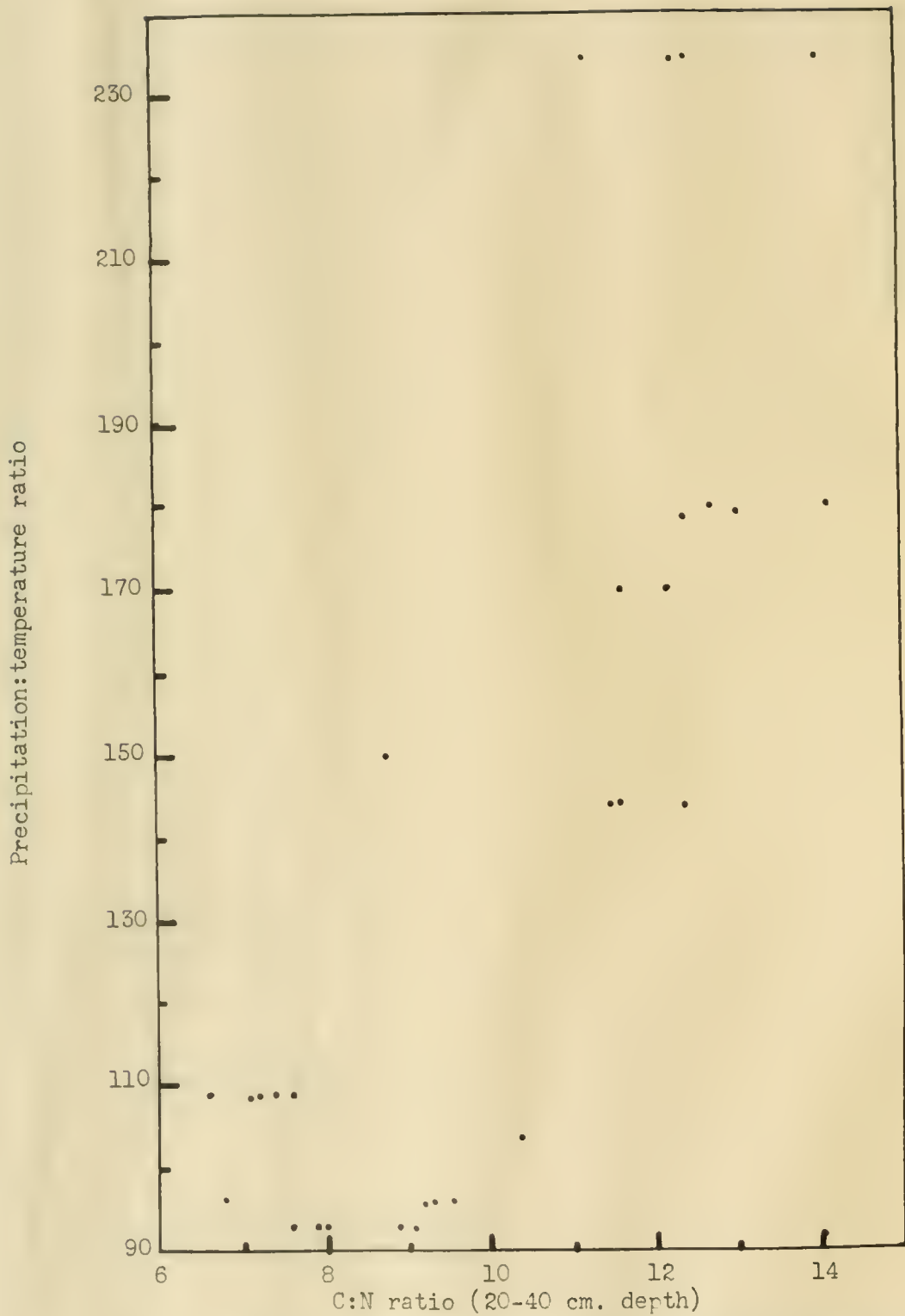


Fig. 4.--Relationship between precipitation:temperature ratios and C:N ratios for the 20 to 40 cm. horizon of Polochic Valley soils.

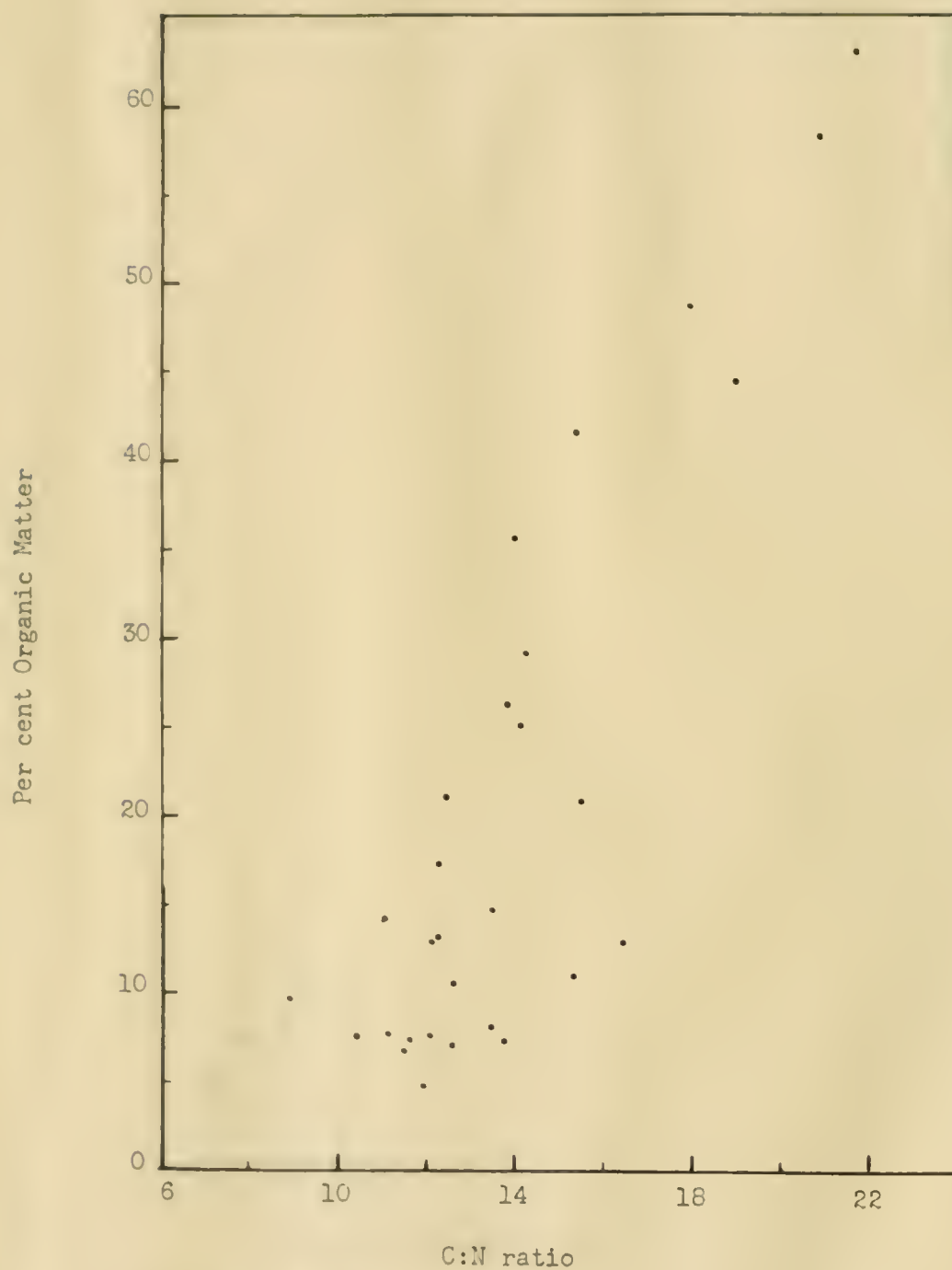


Fig. 5.--Relationship between organic matter and C:N ratios in Polochic Valley topsoils.

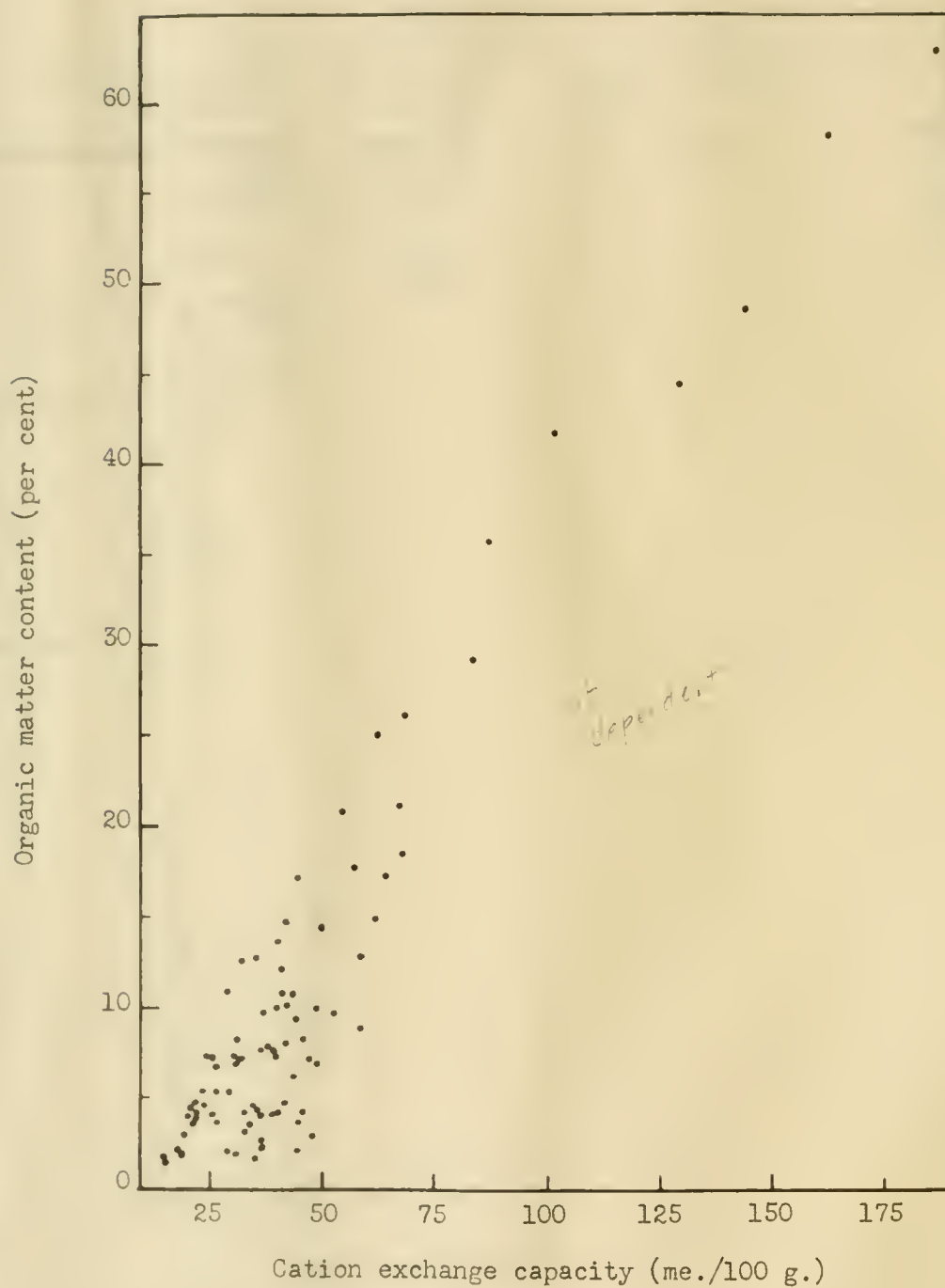


Fig. 6.--Relationship between organic matter content and cation exchange capacity for Polochic Valley soils.

TABLE 6

EXCHANGE CAPACITY AND BASE SATURATION OF POLOCHIC VALLEY
SOILS UNDER THREE STAGES OF SHIFTING CULTIVATION

Location	Exchange Capacity				Base Saturation		
	Depth	Forest	Cleared	2-year	Forest	Cleared	2-year
	cm.	me./ 100g.	Land me./ 100g.	2nd Growth me./ 100g.	Per- cent	Land Per- cent	2nd Growth Per- cent
Los Alpes	0-5	187	130	162	13	33	22
	5-20	68	50	59	4	14	4
	20-40	42	40	36	3	3	12
Seamay	0-5	41	32	31	17	16	24
	5-20	25	27	30	13	8	17
	20-40	22	27	19	5	4	9
Matanzas I	0-5	64	53	45	88	79	81
	5-20	49	44	35	74	72	72
	20-40	46	45	38	65	96	57
Matanzas II	0-5	84	59	62	97	106	87
	5-20	39	47	49	117	80	89
	20-40	26	45	48	109	75	121
Actelá	0-5	54	33	-	33	46	-
	5-20	41	28	-	16	18	-
	20-40	31	24	-	7	9	-
Camelias I	0-5	102	69	-	4	6	-
	5-20	45	40	-	2	3	-
	20-40	42	31	-	2	3	-
Camelias II	0-5	87	62	-	7	7	-
	5-20	57	42	-	2	2	-
	20-40	44	42	-	3	3	-
Average of First Four Fields	0-5	94	69	75	54	59	54
	5-20	45	42	43	52	44	46
	20-40	34	39	35	46	45	50
Average of All Fields	0-5	88	63	-	37	42	-
	5-20	46	40	-	33	28	-
	20-40	36	36	-	28	28	-

The large amount of interstratified three-layer silicate clay minerals in the Polochic Valley soils probably contributes to their high exchange capacities. As might be predicted, exchange capacities are lowest in Seamay, where kaolinite is the dominant clay mineral.

Changes in exchange capacity during the shifting cultivation cycle can usually be associated with changes in organic matter contents. Thus, the average exchange capacity of the topsoil at seven sites drops from 88 me. per 100 g. for forested locations to 63 me. per 100 g. for cleared land. The respective organic matter averages are 30.2 and 18.6 per cent (Table 4). Very little changes in exchange capacity occur in deeper horizons. Young second growth has little effect on exchange capacities. However, second growth older than two years would probably increase exchange capacities, as the forest litter increased the total amount of organic matter.

The shifting cultivation cycle does not appear to have much effect on base saturation of the exchange complex (Table 6). Although base saturation of some soils is increased by clearing, other sites undergo a small decrease.

The cation exchange capacity and per cent base saturation data are not very useful in evaluating the fertility status of Polochic Valley soils. The exceptionally high cation exchange capacities of these soils are associated with the large amounts of organic matter. As such, the exchange capacities are unstable and sensitively reflect small changes in organic matter caused by the shifting cultivation cycle. Furthermore, organic matter has very little permanent charge,

but an extraction at pH 7 measures large amounts of pH-dependent charge (Coleman et al., 1958), misrepresenting field conditions on normally acid soils. As a result, there is no apparent correlation between cation exchange capacity and total exchangeable bases. The values for "per cent base saturation of the exchange complex," in addition to the above limitations, give no measure of the absolute quantities of nutrients available for plant growth and must be interpreted in terms of clay mineral types. Seemingly applicable to these data is the contention of Coleman et al., (1958, 1959) that the amount of permanent charge and its degree of saturation with nutrient bases provide a more realistic basis than total exchange capacity and per cent base saturation for assessing the fertility status of soils. Additional data relating to this point are presented in the next section.

Soil acidity

The pH of soil in the Polochic Valley was measured separately in distilled water and in a weak salt solution of 0.01 M CaCl_2 . The data are given in Table 7. Since soil reaction varies with salt content (Coleman and Mehlich, 1957), the values obtained in CaCl_2 are less affected by unknown variations in the salt content of these soils than pH values obtained in distilled water. Therefore, the former pH values are used in the following comparisons.

The average pH in the topsoil at seven sites increased from 5.0 in forested lands to 5.5 for cleared areas, though little effect was noticeable at deeper depths. This is in agreement with work previously cited from many other areas. Burning may be beneficial on

TABLE 7

VALUES OF pH FOR POLOCHIC VALLEY SOILS UNDER
THREE STAGES OF SHIFTING CULTIVATION

Location	Depth	Soil pH (.01M CaCl ₂)			Soil pH (H ₂ O)		
		Forest	Cleared Land	2-year 2nd Growth	Forest	Cleared Land	2-year 2nd Growth
Los Alpes	0-5	3.9	5.4	4.7	4.4	5.7	4.9
	5-20	3.8	4.3	4.3	4.2	4.7	4.7
	20-40	4.1	4.6	5.2	4.6	5.1	5.5
Seamay	0-5	4.8	5.1	5.3	5.1	5.5	5.5
	5-20	4.6	4.5	4.8	5.0	4.9	5.3
	20-40	4.4	4.4	4.5	5.0	5.0	5.2
Matanzas I	0-5	6.7	7.1	6.8	6.6	7.1	6.6
	5-20	6.5	6.5	6.6	6.4	6.6	6.6
	20-40	6.7	7.2	6.6	6.7	7.3	6.7
Matanzas II	0-5	7.1	7.2	6.4	7.0	7.3	6.3
	5-20	7.3	6.7	6.6	7.3	6.6	6.6
	20-40	7.4	7.1	6.7	7.5	7.2	6.9
Actelá	0-5	5.2	5.5	-	5.3	5.7	-
	5-20	4.8	4.8	-	5.2	5.1	-
	20-40	4.7	4.7	-	5.3	5.2	-
Camelias I	0-5	3.6	4.0	-	4.2	4.5	-
	5-20	4.1	4.5	-	4.5	5.0	-
	20-40	4.6	4.8	-	5.1	5.1	-
Camelias II	0-5	4.0	4.4	-	4.5	4.8	-
	5-20	4.6	4.5	-	5.0	5.0	-
	20-40	4.6	4.7	-	5.0	4.9	-
Average of First Four Fields	0-5	5.6	6.2	5.8	5.8	6.4	5.8
	5-20	5.6	5.5	5.6	5.7	5.7	5.8
	20-40	5.7	5.8	5.8	6.0	6.2	6.1
Average of All Fields	0-5	5.0	5.5	-	5.3	5.8	-
	5-20	5.1	5.1	-	5.4	5.4	-
	20-40	5.2	5.4	-	5.6	5.7	-

very acid soils due to the creation of less acid conditions and the concomitant decrease in the solubility of aluminum. The topsoil pH in four Polochic Valley sites drops from 6.2 for cleared land to 5.8 for two-year second growth. The invasion of cleared soils by vegetation generally tends to lower the pH, though one site (Seamay) showed an increase. Values of pH would probably be depressed still further, and more nearly resemble forest soil values, if more than two years had elapsed since second growth had invaded the forest clearings.

Parent material, topography and climate have a very marked effect on the pH of the immature soils in the Polochic Valley. Soils at Matanzas I and II occur on steep slopes in the driest part of the valley and limestone is very near the surface. Consequently, the pH of these soils is near neutral. However, the soils of Los Alpes also occur over limestone, but under a higher rainfall and on slopes that are not so steep. Consequently, these soils are very deep and the most acid found in this study.

A clearer picture of the difference in pH values (ΔpH) obtained in distilled water and in 0.01 M CaCl_2 is provided in Figure 7 where this difference is related to the soil acidity (0.01 M CaCl_2). The relationship is linear with increasing pH differences in the more acid soils. Apparently these acid soils contained insignificant amounts of soluble salts and exchangeable hydrogen and aluminum displaced by the neutral salt (0.01 M CaCl_2) probably accounts, to a large degree, for the pH differences. The use of a weak calcium salt solution has several advantages. Soil pH, measured in a standard salt solution, does

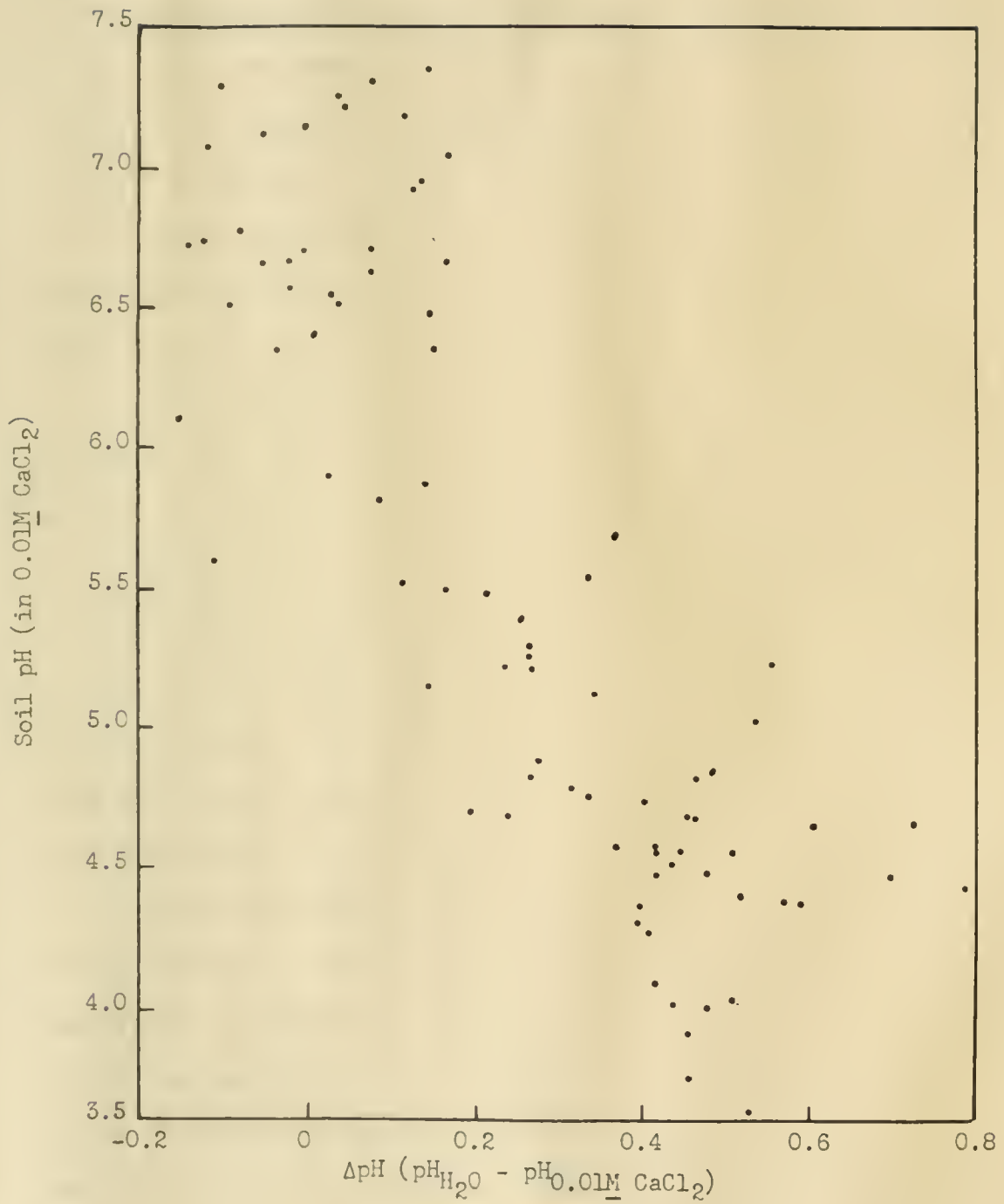
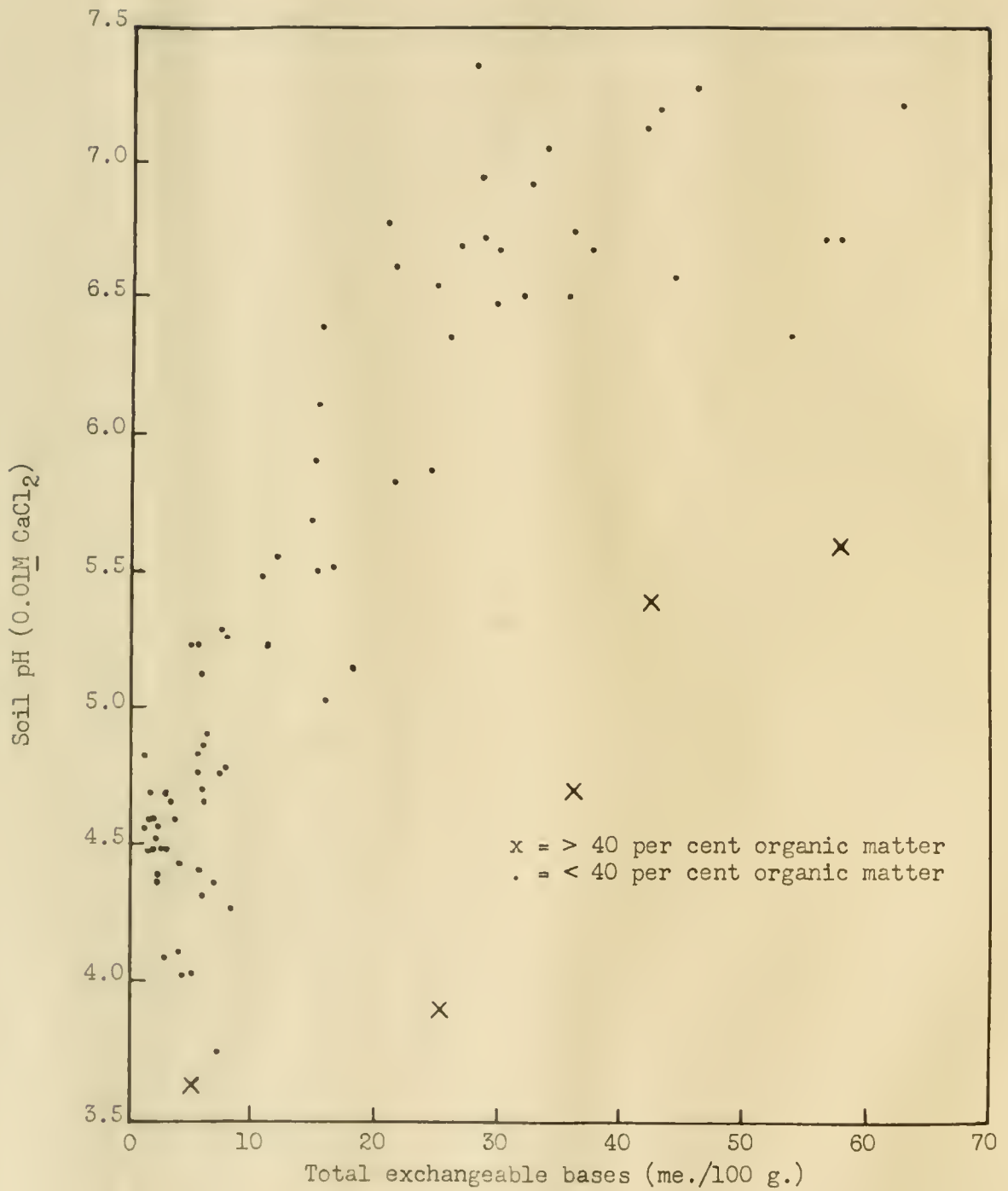


Fig. 7.--Differences between pH measured in distilled water and in 0.01M CaCl_2 for soils of varying acidity in the Polochic Valley

not fluctuate with soil-water ratio or salt content, and is free of suspension effects. "Calcium is the most abundant basic metal cation in most soils, and addition of calcium solutions does not usually change the proportions of the exchangeable cations very much"(Coleman and Mehlich 1957).

Soil pH measurements are diagnostically useful because they are related to other soil properties. Plant growth is not affected much by changes in concentrations of hydrogen ion per se (Arnon, quoted by Allaway, 1957) but rather by associated changes in concentration of other cations. The relation of pH to the sum of the cations (calcium, magnesium, potassium, sodium, and aluminum) for Polochic Valley soils is shown in Figure 8. The sum of the above cations probably indicates the "effective" cation exchange capacity. The cations are held only by permanent charges below a pH of approximately 5.5, and are relatively low in this range, whereas above this pH, they are held by permanent charges plus any other charges which develop (pH-dependent charges) (Coleman et al., 1958).

Cation exchange capacities, measured by extraction with normal ammonium acetate at pH 7.0, do not distinguish between permanent charges and pH-dependent charges. Consequently, the exchange complex of the very acid soils is only slightly saturated with cations. Figure 9 illustrates this point. pH values are plotted against per cent base saturation, a comparison often used for predicting lime requirements (Peech, 1948). Base saturations are below 35 per cent when pH values are less than 5.0. The graph in Figure 9 is very similar to the curve shown by Coleman and Mehlich (1957) for organic matter.



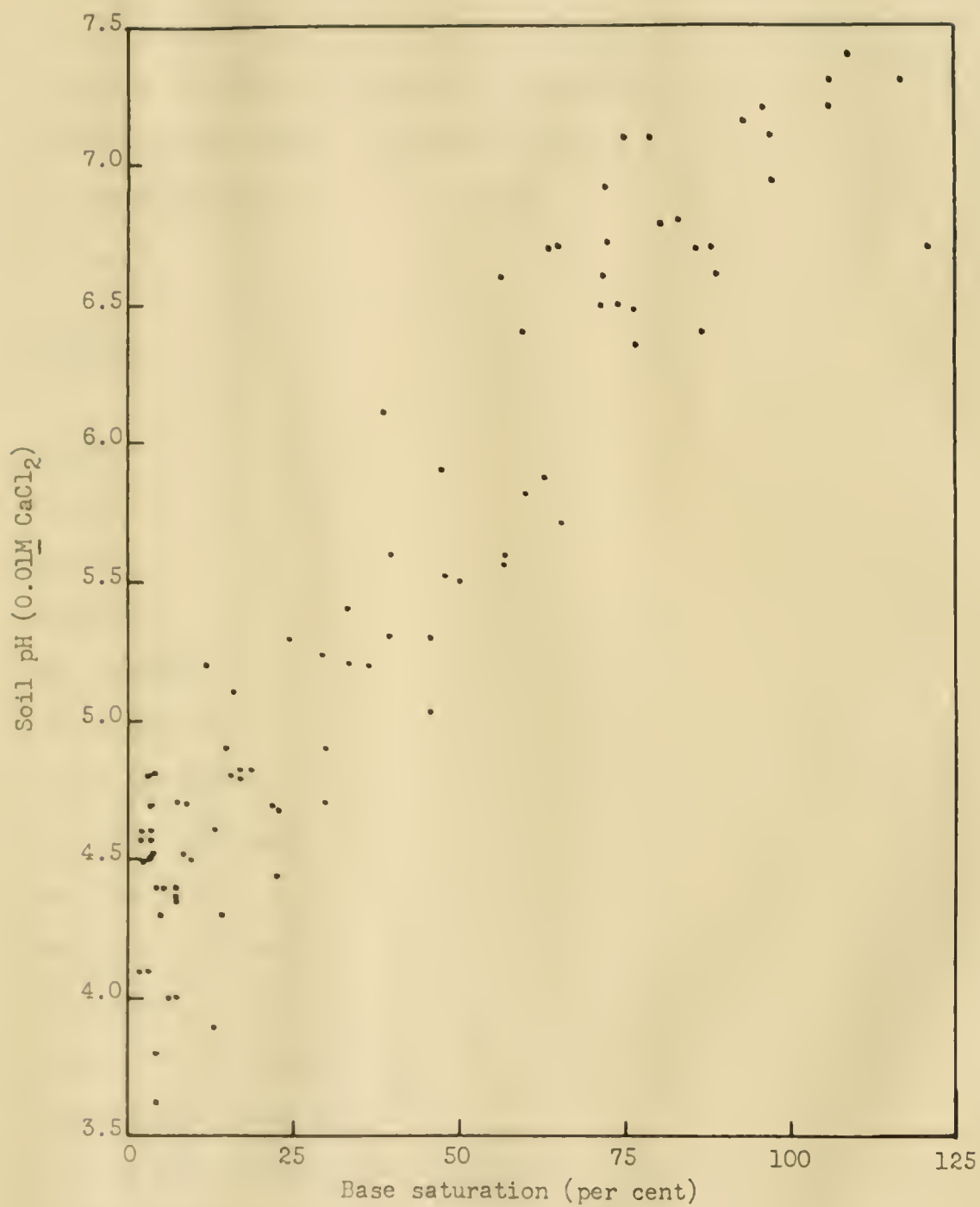


Fig. 9.--Relationship between pH and per cent base saturation (Ca, Mg, K, Na) of cation exchange capacity for Polochic Valley soils.

Apparently soil pH is a more useful measure of soil fertility status in the Polochic Valley than organic matter content or total exchange capacity. Close relationships also exist between soil pH and exchangeable aluminum and calcium; these will be presented in later sections.

Aluminum

Contents of exchangeable aluminum (extracted with $\underline{\text{N}}$ KCl) are highly variable in soils of the Polochic Valley (Table 8) as might be expected from the wide range of pH values. Highest concentrations are found at Los Alpes where one sample contains 418 ppm. Since corresponding pH values are usually less than 5, it is quite possible that aluminum toxicity may be one of the major deterrents to good * crop production in this area. The lowest aluminum values are found on the calcareous soils of Matanzas I and II. It is interesting to note that exchangeable aluminum on these soils of high pH is as much as 15 to 30 ppm. This possibly indicates an inherent weakness in the methodology, especially at low concentrations of extractible aluminum. In addition, the low total metal cation saturation of some of the more acid soils would suggest that the relatively larger amounts of exchangeable aluminum extracted from these soils are, nevertheless, underestimates of the amount of aluminum on the exchange complex. Data of Yuan (1959) indicated that all exchangeable aluminum is not immediately displaced from the soil by a neutral salt extraction, even with seven successive leachings. The chemistry of exchangeable aluminum in the soil is not as yet fully understood.

TABLE 8
EFFECT OF SHIFTING CULTIVATION ON EXCHANGEABLE ALUMINUM
IN POLOCHIC VALLEY SOILS

Location	Exchangeable Aluminum ^a				Aluminum Saturation of the Exchange Complex		
	Depth	Forest	Cleared	2-year	Forest	Cleared	2-year
	cm.	ppm.	Land ppm.	2nd Growth ppm.	Per- cent	Per- cent	Per- cent
Los Alpes	0-5	72	48	59	0.4	0.4	0.4
	5-20	418	147	304	6.8	3.3	5.7
	20-40	251	92	47	6.6	2.6	1.4
Seamay	0-5	78	60	40	2.1	2.1	1.5
	5-20	70	92	34	3.1	3.8	1.3
	20-40	90	101	72	4.5	4.1	4.2
Mantanzas I	0-5	29	22	27	0.5	0.5	0.7
	5-20	24	15	30	0.6	0.4	0.9
	20-40	16	20	16	0.4	0.5	0.5
Mantanzas II	0-5	27	27	22	0.4	0.5	0.4
	5-20	17	19	26	0.5	0.4	0.6
	20-40	18	30	23	0.8	0.7	0.5
Actelá	0-5	39	50	-	0.8	1.7	-
	5-20	75	43	-	2.0	1.7	-
	20-40	93	80	-	3.4	3.7	-
Camelias I	0-5	60	59	-	0.7	1.0	-
	5-20	167	56	-	4.1	1.6	-
	20-40	35	39	-	0.9	1.4	-
Camelias II	0-5	64	55	-	0.8	1.0	-
	5-20	70	86	-	1.4	2.3	-
	20-40	51	53	-	1.3	1.4	-
Average of First Four Fields	0-5	52	39	37	0.9	0.9	0.8
	5-20	132	68	99	2.8	2.0	2.1
	20-40	94	61	40	3.1	2.0	1.7
Average of All Fields	0-5	53	46	-	0.8	1.0	-
	5-20	120	65	-	2.6	1.9	-
	20-40	79	59	-	2.6	2.1	-

^aExtracted with 1 N KCl.

The average exchangeable aluminum in the topsoil of Polochic Valley sites declines from 53 ppm. for forested land to 46 ppm. for cleared fields. This relatively small reduction in exchangeable aluminum occurs in the topsoil of all fields except Actelá. Greater fluctuations in exchangeable aluminum occur deeper within the soil profile, but no consistent trend is apparent. Destruction of plant material by fire and the resultant increase in soil pH may be partially responsible for the reduction of exchangeable aluminum in the surface soil. As shown in Figure 10, exchangeable aluminum is closely related to the pH of Polochic Valley soils, especially in the more acid soils where concentrations of aluminum are larger. However, samples from very acid topsoils containing more than 25 per cent organic matter have much less aluminum than soils of comparable pH values but with less organic matter.

The equation for the curve in Figure 10 was obtained by plotting the data in a manner to yield a straight line which was fitted by least squares (Figure 11). Aluminum values from Matanzas II were omitted from Figure 11 so that the graph could be compared with a similar plot of calcium data presented later. The equation calculated from the line when aluminum is given in milliequivalents is:

$$\text{pH} = \frac{\text{Al}}{0.256 \text{ Al} - 0.027} .$$

When aluminum is expressed in parts per million the equation is:

$$\text{pH} = \frac{\text{Al}}{0.256 \text{ Al} - 2.43} .$$

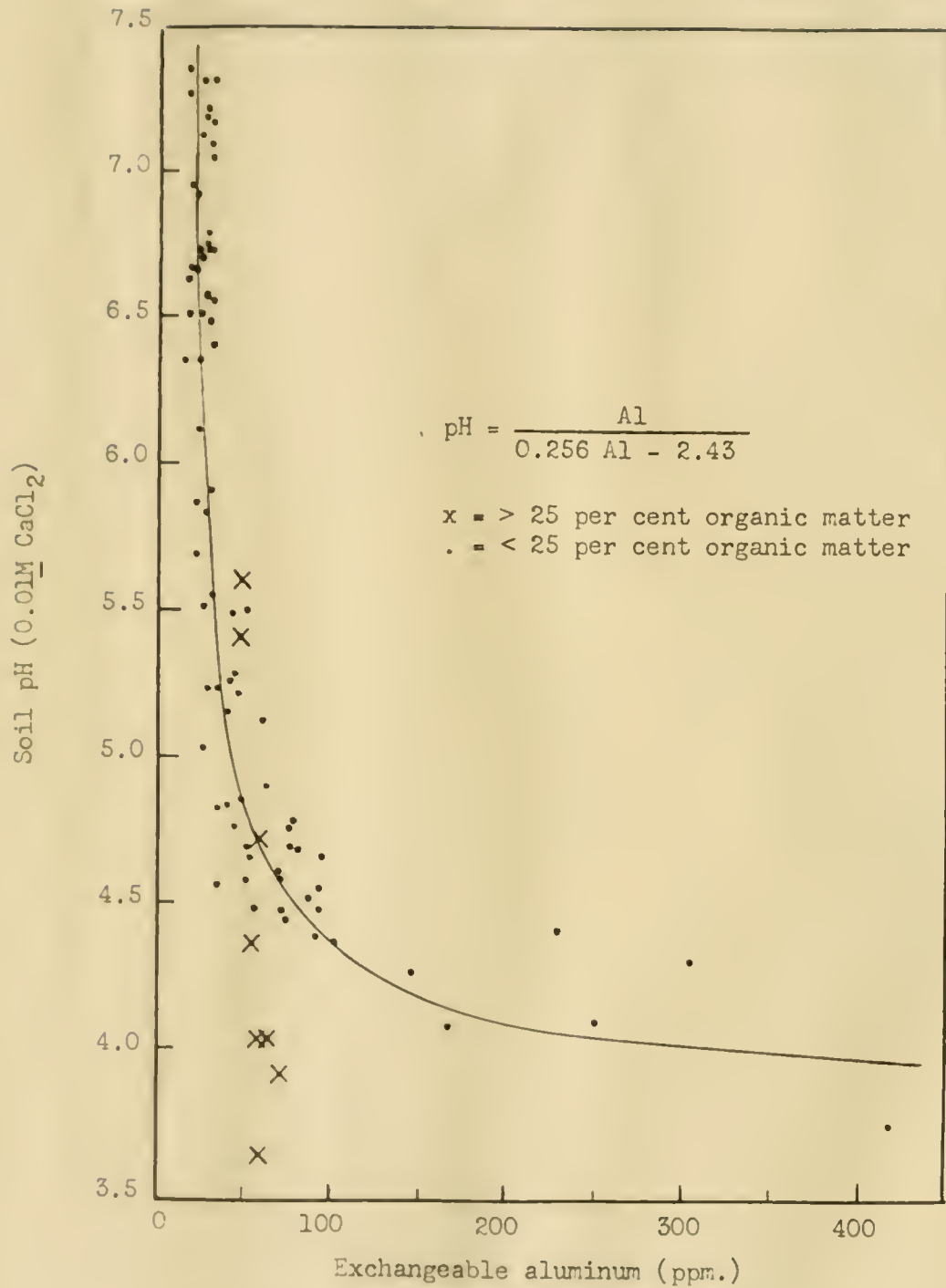


Fig. 10.--Relationship of pH to IN KCl exchangeable aluminum in Polochic Valley soils.

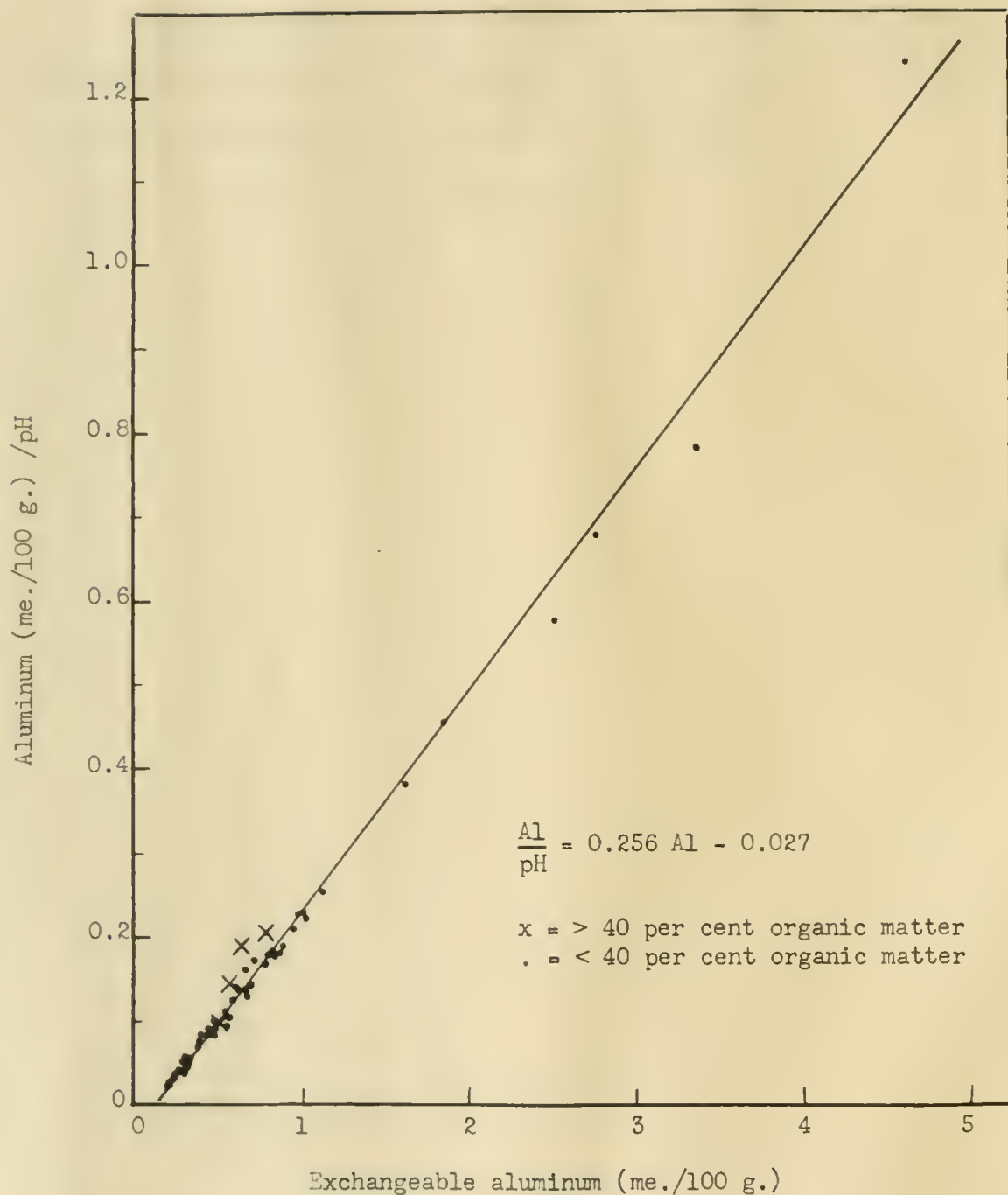


Fig. 11.--Exchangeable aluminum per unit of pH plotted against exchangeable aluminum for Polochic Valley soils (excluding Matanzas II).

The relationship shown in Figure 10 is very similar to the aluminum solubility curve of Magistad (1925), though Magistad's curve was derived from treating aluminum sulfate with different concentrations of sodium hydroxide. Three possibilities are suggested by this similarity: (1) it is accidental, (2) soil pH is the result of the amount of aluminum dominating the exchange complex of the clay colloids, and (3) aluminum solubility is a function of the pH of the soil solution as indicated by the data of Magistad (1925) and Pierre et al. (1932).

Calcium

Concentrations of exchangeable calcium are generally highest in the top 5 cm. of Polochic Valley soils and diminish rapidly with depth (Table 9). Since the soils of Los Alpes and Matanzas I and II are derived from limestones, they have much higher concentrations of exchangeable calcium than the other soils derived from phyllites and schists (Seamay, Actelá, Camelias I and II).

Calcium saturation of the exchange complex in the Polochic Valley is quite low for agricultural soils. All soils with the exception of Matanzas I and II have a calcium saturation of less than 35 per cent. Camelias I and II have the lowest values of less than 5 per cent. These latter two soils have less than 100 ppm. exchangeable calcium at a depth of 5 to 20 cm.; much lower than the value of 400 ppm. which Gethin Jones (1949) arbitrarily suggested as the minimum for agriculture in Kenya. Possibly, calcium is one of the limiting factors for good crop production on Camelias I and II.

TABLE 9

EXCHANGEABLE CALCIUM AND PERCENT CALCIUM SATURATION
OF THE SOIL EXCHANGE COMPLEX UNDER THREE STAGES
OF SHIFTING CULTIVATION IN THE POLOCHIC VALLEY

Location	Exchangeable Calcium				Calcium Saturation		
	Depth	Forest	Cleared	2-year	Forest	Cleared	2-year
	cm.	ppm.	Land ppm.	Growth ppm.	Per- cent	Land Per- cent	Growth Per- cent
Los Alpes	0-5	3280	5725	4830	8.8	22.0	14.9
	5-20	362	952	333	2.6	9.6	2.9
	20-40	157	151	656	1.9	2.0	9.2
Seamay	0-5	912	761	1131	11.2	11.9	18.1
	5-20	399	271	716	8.0	5.2	12.0
	20-40	96	96	267	2.3	1.9	6.8
Mantanzas I	0-5	8785	6210	5240	68.4	58.5	58.0
	5-20	5520	4530	3545	56.2	51.4	50.6
	20-40	3913	6240	2670	42.4	69.2	35.0
Mantanzas II	0-5	12395	9765	8990	73.5	82.6	72.4
	5-20	6775	5275	7495	86.6	56.0	76.4
	20-40	4405	4640	10370	84.6	51.6	107.9 ^a
Actelá	0-5	2505	2113	-	23.1	31.8	-
	5-20	878	723	-	10.7	12.9	-
	20-40	343	250	-	5.5	5.0	-
Camelias I	0-5	423	344	-	2.1	2.5	-
	5-20	<100	<100	-	1.1	1.3	-
	20-40	<100	<100	-	1.2	1.6	-
Camelias II	0-5	555	573	-	3.2	4.7	-
	5-20	<100	<100	-	0.9	1.2	-
	20-40	<100	<100	-	1.1	1.2	-
Average of First Four Fields	0-5	6343	5615	5048	40.5	43.8	40.9
	5-20	3264	2757	3022	38.4	30.6	35.5
	20-40	2143	2782	3491	32.8	31.2	39.7
Average of All Fields	0-5	4122	3642	-	28.2	30.6	-
	5-20	2019	1707	-	23.7	19.7	-
	20-40	1302	1654	-	19.9	18.9	-

^aPossibly free calcium carbonate present.

The removal of forest vegetation by burning in the Polochic Valley increased the percentage of calcium on the exchange complex in the topsoil of all cleared fields except Matanzas I, although the total exchangeable calcium decreased (with the exception of Los Alpes). A possible explanation for this anomaly is that the fields were sampled in the middle of the cropping season and most of the salts released by the ash had probably been lost by erosion or leaching. The exception at the Los Alpes site, where a large gain in calcium accompanied clearing and burning, was probably due to the fact that this site was sampled sooner after burning than the other sites. Elsewhere, an immediate increase in exchangeable calcium after burning has been reported (Suarez de Castro, 1957; Focan et al., 1950; Heyward and Barnette, 1934), though calcium has been found to leach faster than magnesium or potassium (Suarez de Castro and Rodriguez, 1958; Hardy, 1956).

The decrease in exchange capacity, due to the effects of burning on soil organic matter, was greater than the subsequent loss of calcium. Thus, net gains in calcium saturation of the exchange complex occurred. Since the availability of calcium increases with degree of base saturation (Mehlich and Coleman, 1952), the amount of calcium in cleared land, though less than in forest, should be more readily available to plants.

The data from the Polochic Valley are insufficient to obtain a clear picture of second growth effects on exchangeable calcium.

There is a definite relationship between exchangeable calcium and soil acidity as indicated in Figure 12. The exchangeable calcium

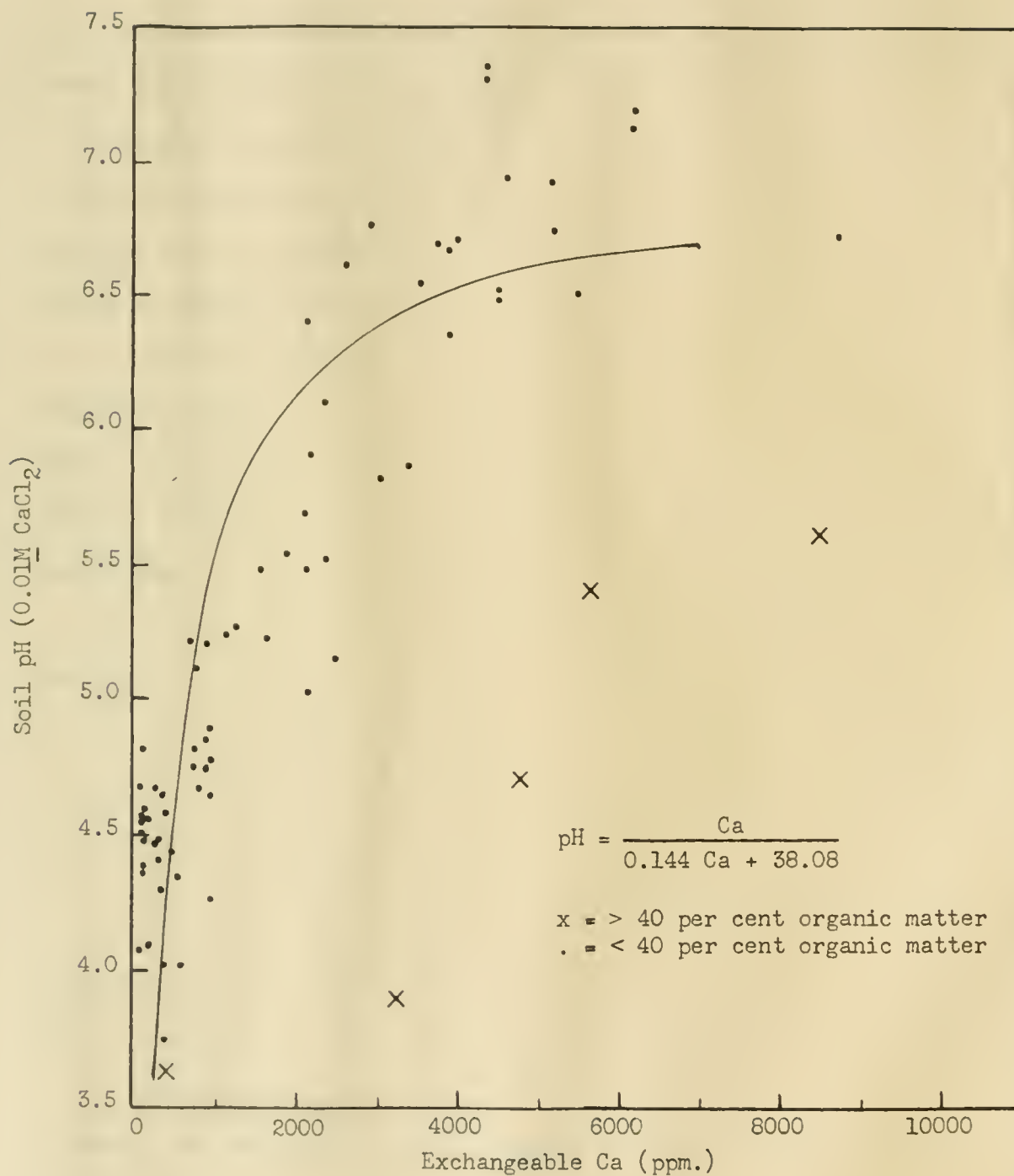


Fig. 12.--Relationship between pH and neutral normal ammonium acetate exchangeable calcium for Polochic Valley soils (excluding Matanzas II).

content increases with pH above a value of 5.0. Soils high in organic matter contain greater amounts of exchangeable calcium than more mineral soils at the same pH. Data from Matanzas II are omitted from Figure 12 because the exchange capacities of some soils there were more than 100 per cent saturated with bases. Possibly, calcium carbonate in these soils dissolved during the extraction procedure.

At pH values below 5, calcium is probably held only by the permanent charge of the clay particles, while at pH values greater than 5, calcium is also held by pH-dependent charges (Coleman and Mehlich, 1957). Most of the pH-dependent charges probably develop in the organic matter which is relatively high in Polochic Valley soils.

Figure 13 contains data of Figure 12 plotted in a different way so that an equation for the special hyperbola indicated in the latter can be derived by linear regression using least squares. The fit to a straight line is good and the resulting equation relating pH to calcium (me./100 g.) is:

$$\text{pH} = \frac{\text{Ca}}{0.144 \text{ Ca} + 0.19}$$

Soils with more than 40 per cent organic matter are not included in the calculations.

The slope of the line relating calcium to pH in Figure 13 is roughly the same as the slope of a line relating aluminum to pH shown in Figure 11. A further indication of the similar, though opposite, relations of exchangeable soil calcium and aluminum with pH is indicated in Figure 14. Calcium makes up a relatively larger

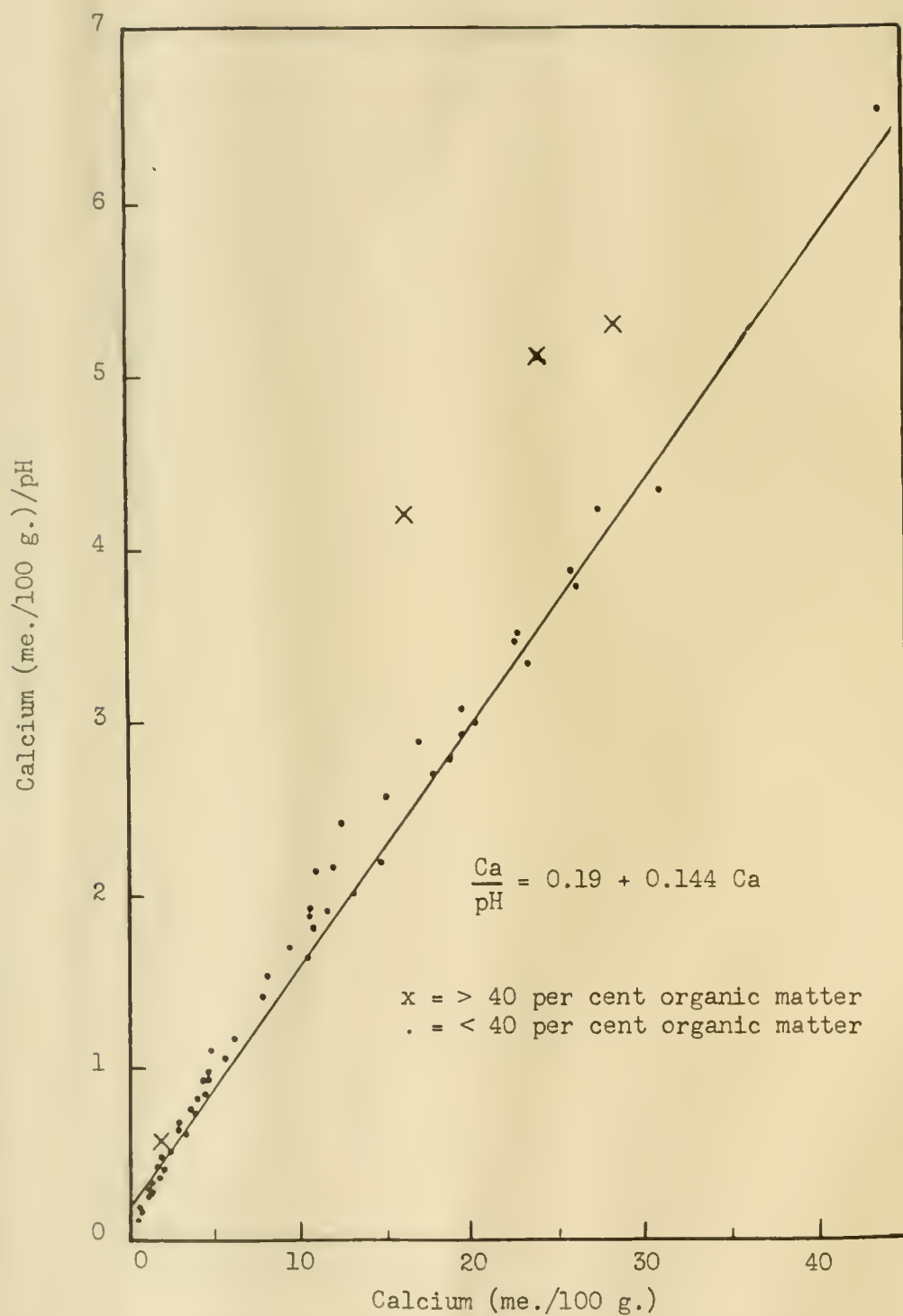


Fig. 13.--Exchangeable calcium per unit of pH plotted against exchangeable calcium for Polochic Valley soils (excluding Matanzas II).

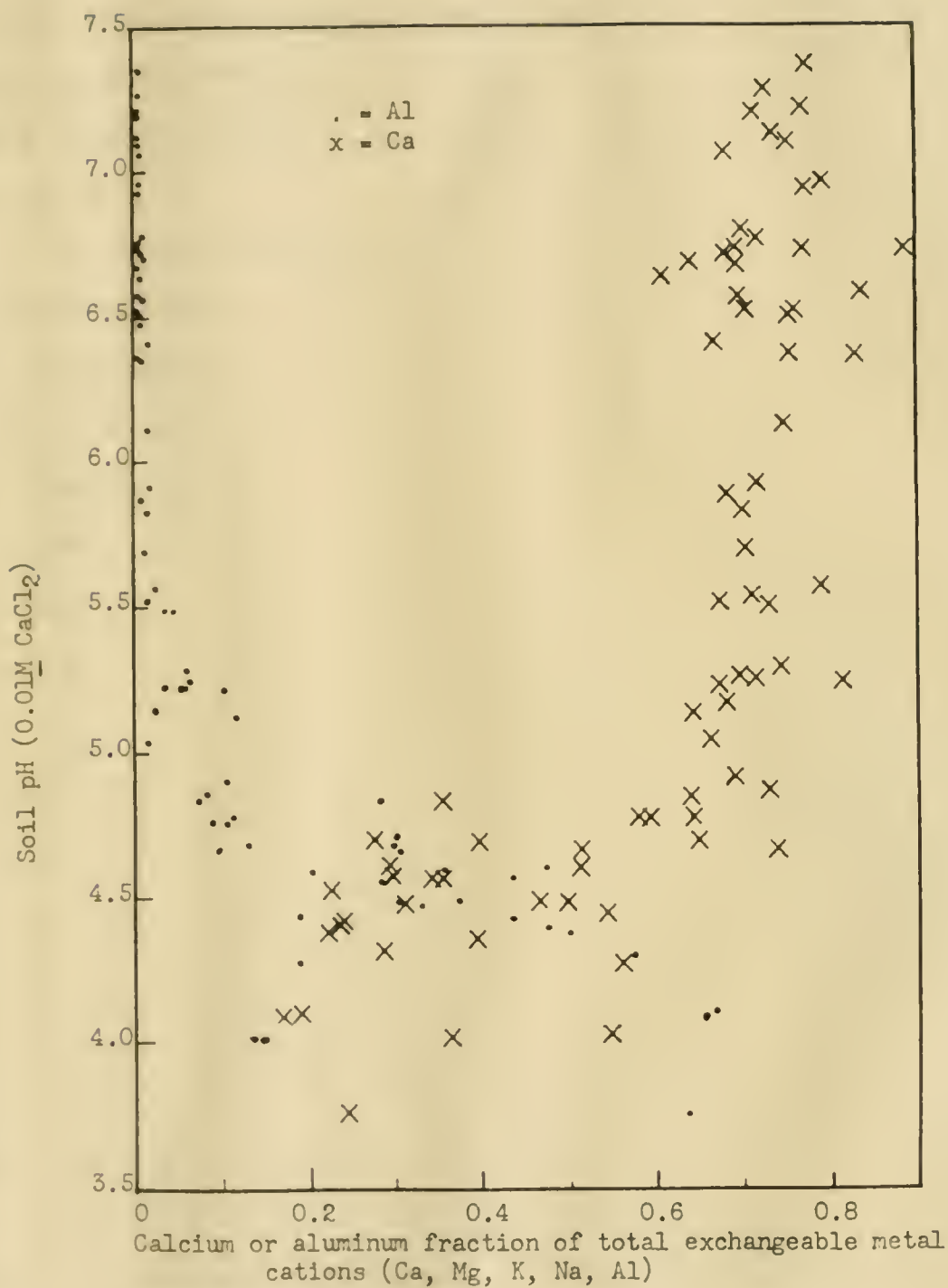


Fig. 14.--Relationship of pH to aluminum and calcium fraction of total exchangeable metal cations (Ca, Mg, K, Na, Al) for Polochic Valley soils with less than 40 per cent organic matter.

fraction of the total exchangeable metal cations at high pH values, whereas aluminum becomes predominant in very acid soils. Aluminum sharply increases and calcium sharply decreases when pH values drop below 5.0.

The above data strongly suggest a relationship between exchangeable calcium and aluminum for Polochic Valley soils. The plot of milliequivalents of calcium against millequivalents of aluminum appears to be hyperbolic (Figure 15). An equation to fit a hyperbola was derived by least squares. Data from soils containing more than 40 per cent organic matter, more than 1.5 me. of aluminum, or less than 1 me. of calcium deviated from a hyperbola and were arbitrarily omitted in calculating coefficients for the following equation:

$$\text{Al}(\text{Ca})^{0.4736} = 1.0641$$

A slight simplification of this equation yields:

$$\text{Al} = \frac{1}{\sqrt{\text{Ca}}}$$

Thus, the level of aluminum, under the conditions fitting the above data, is inversely proportional to the square root of the calcium level. This postulated relationship, arising from a survey of soils in the Polochic Valley, might be tested as a hypothesis, and useful plant relationships revealed, by using more refined techniques. The lack of fit at very low calcium values or high aluminum values may be an indication of inconsistent aluminum and calcium extraction results at different levels of these ions on the soil colloids.

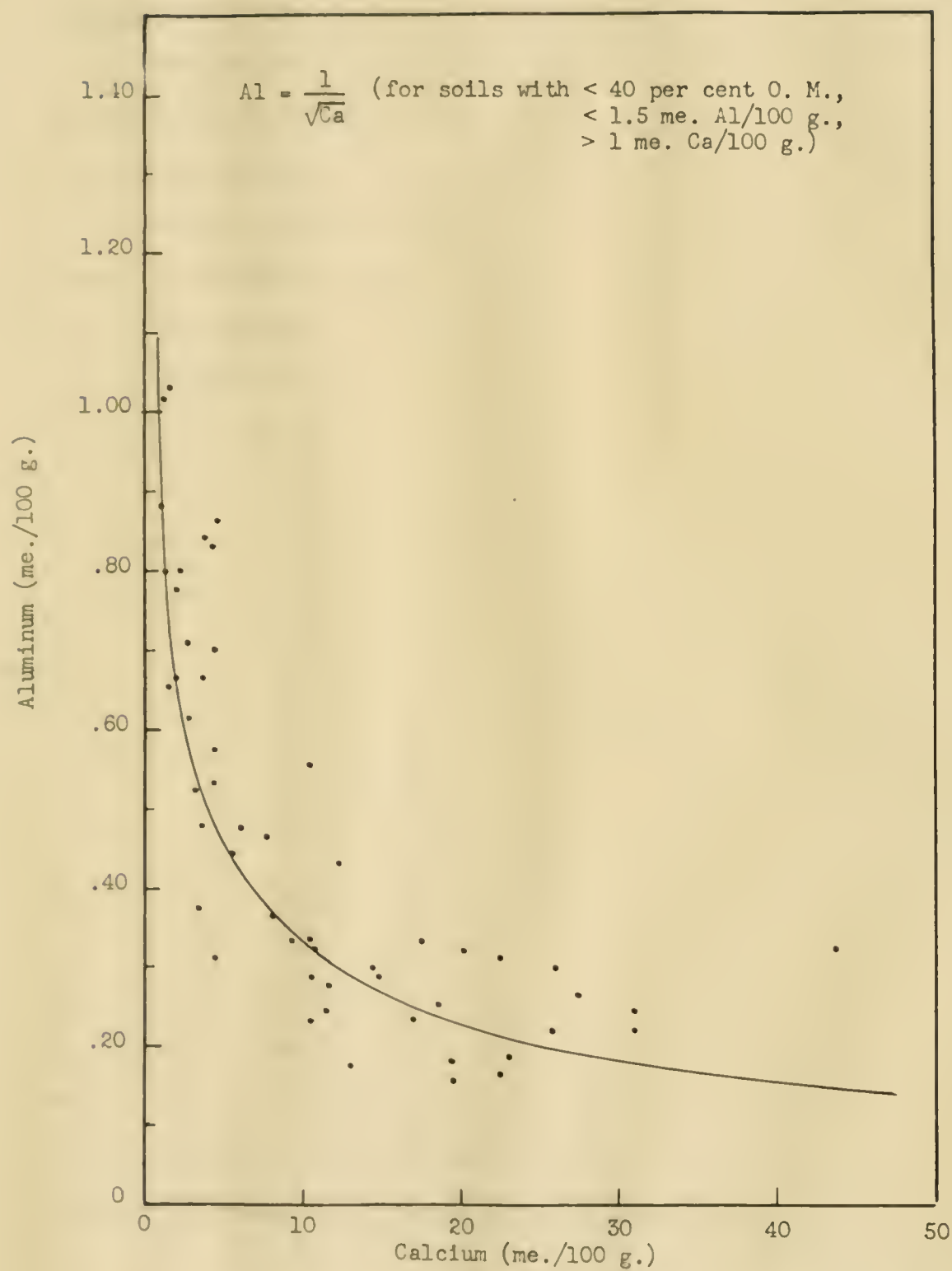


Fig. 15.--Relationship between exchangeable aluminum and calcium in Polochic Valley soils (except Matanzas II).

Magnesium

Magnesium in Polochic Valley soils responds to forest clearing and burning in much the same manner as calcium; there is a slight decline in the topsoils of all fields except for Los Alpes (Table 10). As in the case of calcium, the different results for Los Alpes may possibly be attributed to the fact that it was sampled earlier after burning than the other fields. Workers in other areas have generally found an increase in soil magnesium immediately after the burning of vegetation (Suzrez de Castro, 1957); Focan et al., 1950; Heyward and Barnette, 1934). The effect of young second growth on magnesium is not apparent from the Polochic Valley data.

Levels of magnesium in the more acid soils are highest in the topsoil (probably concentrated there by the forest vegetation) and decrease with depth. Soils derived from limestones (Los Alpes, Matanzas I and II) contain the largest amounts of magnesium and there is less decrease with depth, as might be expected.

Potassium and sodium

Soils of the Polochic Valley are characteristically much richer in exchangeable potassium in the surface 5 cm. than throughout the remainder of the profile (Table 11). Potassium values for cleared fields range from as low as 48 ppm. for Seamay to 834 ppm. for Los Alpes, though levels generally are high. The profile distribution of exchangeable potassium is similar to the organic matter distribution.

TABLE 10
EFFECTS OF SHIFTING CULTIVATION ON EXCHANGEABLE MAGNESIUM
IN POLOCHIC VALLEY SOILS

Location	Depth	Exchangeable Magnesium		2-year 2nd Growth
		Forest	Cleared Land	
	cm.	ppm.	ppm.	ppm.
Los Alpes	0-5	652	1083	990
	5-20	86	90	77
	20-40	38	25	101
Seamay	0-5	194	117	140
	5-20	80	38	126
	20-40	32	54	34
Mantanzas I	0-5	1057	966	860
	5-20	728	891	709
	20-40	1108	1213	825
Matanzas II	0-5	1952	1306	679
	5-20	1170	1135	477
	20-40	563	1042	336
Actelá	0-5	442	322	-
	5-20	176	106	-
	20-40	38	70	-
Camelias I	0-5	176	166	-
	5-20	< 25	< 25	-
	20-40	< 25	< 25	-
Camelias II	0-5	259	105	-
	5-20	< 25	< 25	-
	20-40	< 25	< 25	-
Average of First Four Fields	0-5	964	868	667
	5-20	516	539	347
	20-40	435	334	324
Average of All Fields	0-5	676	581	-
	5-20	327	330	-
	20-40	261	208	-

TABLE 11
EXCHANGEABLE POTASSIUM AND SODIUM OF SOILS
UNDER THREE STAGES OF SHIFTING CULTIVATION
IN THE POLOCHIC VALLEY

Location	Exchangeable Potassium				Exchangeable Sodium		
	Depth	Forest	Cleared	2-year	Forest	Cleared	2-year
	cm.	ppm.	Land	Growth	ppm.	Land	Growth
Los Alpes	0-5	337	834	517	353	544	460
	5-20	44	237	32	28	183	8
	20-40	22	40	36	36	58	46
Seamay	0-5	110	48	90	110	60	108
	5-20	36	32	41	64	40	126
	20-40	17	30	30	50	8	34
Matanzas I	0-5	388	516	406	662	352	400
	5-20	193	230	170	418	313	257
	20-40	120	170	100	256	376	243
Matanzas II	0-5	286	224	210	680	634	634
	5-20	116	116	124	544	384	590
	20-40	44	96	90	330	370	686
Actelá	0-5	250	272	-	274	258	-
	5-20	80	78	-	127	100	-
	20-40	40	50	-	52	54	-
Camelias I	0-5	237	110	-	93	116	-
	5-20	44	42	-	40	42	-
	20-40	40	50	-	54	47	-
Camelias II	0-5	334	160	-	170	83	-
	5-20	60	44	-	70	34	-
	20-40	56	64	-	103	43	-
Average of First Four Fields	0-5	280	406	306	451	398	400
	5-20	97	154	92	264	230	245
	20-40	51	84	64	168	203	250
Average of All Fields	0-5	277	309	-	335	292	-
	5-20	82	111	-	184	157	-
	20-40	48	71	-	122	129	-

Most soils of the Polochic Valley contain large amounts of three-layer silicates. Since hydrous micas contain approximately 6 per cent potash (Buehrer, 1955), the breakdown of these clay minerals by active weathering in the humid, tropical climate of the Polochic Valley probably accounts for some of the high potassium levels found there. Seamay soils contain the lowest levels of potassium which, no doubt, can be attributed to the presence of kaolin as the dominant clay mineral. Levels of exchangeable potassium found in the Polochic Valley soils are comparable to those reported for latosols in southern China (Lee, 1950).

Although one would surmise that clearing and burning would deposit large amounts of exchangeable potassium in the topsoil, the only noticeable effect in soils of the Polochic Valley appears to be an increase of exchangeable potassium in the 20 to 40 cm. horizon, probably through leaching. All locations show this trend and the average for seven locations increases from 51 ppm. for soils under forest to 84 ppm. for cleared land. Although clearing markedly increases exchangeable potassium in the topsoil of some locations (Los Alpes, Matanzas I), there is a marked decrease of at least 50 per cent elsewhere (Seamay, Camelias I and II). Burning vegetation releases much potassium but the results here indicate that it quickly moves down the profile or is lost by erosion. However, other investigators (Suarez de Castro, 1957; Focan, et al., 1950) have found increases in topsoil potassium from burning. In this study, the results for young secondary vegetation are inconclusive; possibly,

a longer period of time under second growth will restore the higher potassium levels existing under the original forest.

The relative magnitudes of exchangeable potassium and sodium (Table 11) are approximately the same but sodium, unlike potassium, shows little correlation with the stage of shifting cultivation.

Manganese and zinc

The 0.1N HCl-extractible manganese and zinc contents in Table 12 apparently are not related to the shifting cultivation cycle. The manganese data seem to indicate a highly variable manganese content in these soils. In all cases, however, the amounts of manganese are considered to be in a range which is nontoxic and yet sufficient for normal plant growth. Apparently, deficiencies of manganese are very rare in the Polochic Valley as revealed by H. Mowry¹ in a survey of minor element deficiencies of coffee trees.

Highest concentrations of extractible manganese occur in the upper 5 cm. of Polochic Valley soils. A similar profile distribution was found in Ghana forest soils by Endredy and Montgomery (1954). Although a correlation between manganese and organic matter (Table 4) is not obvious, the high concentrations of the former in the topsoil would lead one to suspect that it is accumulated there in litter deposited by plants. No apparent correlation is found between manganese and aluminum (Table 8) in Polochic Valley soils, even though their

¹H. Mowry, Former Director, Florida Agricultural Experiment Stations. Survey results presented in seminar before Servicio Cooperativo Interamericano de Agricultura in Guatemala City, August 24, 1956.

TABLE 12
EXTRACTABLE MANGANESE AND ZINC OF SOILS UNDER
THREE STAGES OF SHIFTING CULTIVATION
IN THE POLOCHIC VALLEY

Location	Extractable Manganese ^a				Extractable Zinc ^a		
	Depth	Forest	Cleared	2-year	Forest	Cleared	2-year
			Land	2nd Growth		Land	2nd Growth
	cm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
Los Alpes	0-5	280	549	532	10.1	8.5	9.8
	5-20	< 3	22	19	2.0	3.3	4.9
	20-40	< 3	< 3	255	6.2	1.6	3.6
Seamay	0-5	124	44	55	3.3	1.3	1.6
	5-20	85	17	36	2.0	2.6	< 0.7
	20-40	28	< 3	28	< 0.7	2.0	< 0.7
Matanzas I	0-5	541	266	387	4.6	5.6	7.5
	5-20	412	225	124	5.2	2.6	3.6
	20-40	170	107	< 3	2.6	2.0	61.8
Matanzas II	0-5	91	167	294	< 0.7	3.6	4.3
	5-20	93	126	195	< 0.7	1.0	2.0
	20-40	52	58	60	1.0	1.3	< 0.7
Actelá	0-5	167	102	-	2.9	2.9	-
	5-20	107	77	-	2.6	1.6	-
	20-40	47	33	-	1.3	< 0.7	-
Camelias I	0-5	33	33	-	6.9	2.9	-
	5-20	< 3	< 3	-	2.3	< 0.7	-
	20-40	6	< 3	-	1.6	< 0.7	-
Camelias II	0-5	91	184	-	4.6	6.5	-
	5-20	17	36	-	2.0	2.3	-
	20-40	14	19	-	< 0.7	1.6	-
Average of First Four Fields	0-5	259	257	317	4.7	4.8	5.8
	5-20	148	97	93	2.5	2.4	2.8
	20-40	63	43	87	2.6	1.7	16.7
Average of All Fields	0-5	189	192	-	4.7	4.5	-
	5-20	103	72	-	2.4	2.0	-
	20-40	46	32	-	2.0	1.4	-

^aExtracted with 0.1 N HCl.

chemical behavior (pH-solubility relations) in soils is very similar. The soils derived from limestone have higher levels of extractible manganese than the soils derived from metamorphic parent rock (schists and phyllites). Possibly, the more acid conditions of the latter soils increased the solubility of manganese and results in greater leaching losses.

The zinc contents of Polochic Valley soils, unlike the manganese contents, are probably in the deficient range, especially when less than one part per million. Also, the absence of a marked difference in the zinc contents at different depths in the soil profile points to a limited plant uptake and subsequent surface deposition of zinc from decaying plant material.

Mowry¹ found zinc deficiency symptoms on coffee trees in the Polochic Valley. It is possible that zinc may limit corn production in several fields (Seamay, Matanzas II, Actelá and Camelias I) where different horizons contain less than one part per million. The contents of zinc in Polochic Valley soils are considerably below the toxic levels reported by Gall and Barnette (1940) on soils of much lower exchange capacities.

Phosphorus

The phosphorus extracted with a 0.03N NH_4F in 0.1N HCl solution (Table 13) does not show any conclusive effects of forest clearing. In some fields (Los Alpes, Matanzas I, Camelias I) there

¹Op. cit.

TABLE 13
EXTRACTABLE PHOSPHORUS UNDER THREE STAGES OF SHIFTING CULTIVATION
IN POLOCHIC VALLEY SOILS

Location	Extractable Phosphorus ^a			
	Depth	Forest	Cleared Land	2-year 2nd Growth
	cm.	ppm.	ppm.	ppm.
Los Alpes	0-5	7.2	55.5	33.9
	5-20	5.3	2.3	2.9
	20-40	2.0	1.5	1.9
Seamay	0-5	6.5	3.8	3.7
	5-20	6.1	1.8	4.6
	20-40	4.2	1.3	1.1
Matanzas I	0-5	14.0	28.8	6.3
	5-20	5.6	30.5	4.0
	20-40	5.3	3.6	5.3
Mantanzas II	0-5	22.9	23.4	9.9
	5-20	9.3	5.5	3.2
	20-40	6.2	7.6	1.6
Actelá	0-5	29.7	31.8	-
	5-20	28.5	3.1	-
	20-40	25.1	18.2	-
Camelias I	0-5	4.0	21.3	-
	5-20	3.0	4.3	-
	20-40	0.7	0.6	-
Camelias II	0-5	56.5	20.5	-
	5-20	4.2	2.8	-
	20-40	2.6	2.7	-
Average of First Four Fields	0-5	12.7	27.9	13.5
	5-20	6.6	10.0	3.7
	20-40	4.4	3.5	2.5
Average of All Fields	0-5	20.1	26.4	-
	5-20	8.9	7.2	-
	20-40	6.6	5.1	-

^a Extracted by method of Bray and Kurtz (1945).

are relatively large increases, while in others (Seamay, Camelias II) there are decreases. The data (with the exception of Seamay) indicate that soil phosphorus generally decreases after two years of second growth, possibly due to the cumulative depletion of soil phosphorus reserves by one corn crop and the succeeding rapidly growing vegetation. Birch (1953) found that phosphorus uptake by grasses in Kenya was not related to soil phosphorus, extracted as above. Instead, he found a highly correlated inverse relation between phosphorus responses on acid soils and base saturation of the cation exchange capacity. Birch's findings might possibly also apply to the Polochic Valley soils.

Extractible soil phosphorus values are higher in Polochic Valley topsoils than at greater depths, suggesting that phosphorus may be associated with organic matter. Such a correlation has been reported from other tropical areas (Nye and Bertheux, 1957; Endredy and Montgomery, 1954).

The relationship between phosphorus and aluminum might be significant for Los Alpes soils. One could hypothesize that under forest, at a very low pH and high concentration of exchangeable aluminum, much of the phosphorus is fixed. However, after clearing, the pH rises, the amount of exchangeable aluminum diminishes, and much phosphorus, which was formerly unavailable, becomes soluble. The increase of extractible phosphorus in Los Alpes topsoil (where aluminum is relatively high, Table 8) from 7.2 ppm. under forest to 55.5 ppm. for the cleared field may be attributed to this mechanism.

Physical Soil Factors

The significance of soil physical properties in soil-plant relationships is probably the most important unknown factor in proper land management of the earth's warm, humid regions. Almost any problem of chemical fertility can be solved if cost is no object. However, accurate data on the long-term effect of cultivation and chemical amendments on the excellent structure of many virgin tropical soils is still lacking. This problem will have to be solved before long-range management practices can be predicted for some of the large unused tropical areas, such as the Amazon Basin.

Many generalizations have been written about the influence of shifting cultivation on soil structure but little actual field work has been reported. Most of the serious field studies on the effects of burning on soil structure have shown that detrimental effects are few, and many times the practice is beneficial. No doubt, the absence of tillage in shifting cultivation is a very important factor in limiting the amount of structural deterioration that takes place during cropping. Most effects of shifting cultivation on structure can probably be attributed to changes taking place in the organic or iron oxide components of the soil.

Bulk density

Although bulk density values for Polochic Valley soils appear to be very low (Table 14), this is to be expected for forest soils (Lutz and Chandler, 1946). The samples were taken at depths of 5 to 10 cm. Bulk density values are increased somewhat by forest clearing,

TABLE 14

BULK DENSITY VALUES OF POLOCHIC VALLEY SOILS UNDER
THREE STAGES OF SHIFTING CULTIVATION

Location	Bulk Density		
	Forest	Cleared Land	2 Year 2nd Growth
	g./cc.	g./cc.	g./cc.
Los Alpes	0.20	0.42	0.33
Seamay	0.66	0.70	0.89
Matanzas I	0.87	0.78	0.75
Matanzas II	0.52	0.94	0.82
Actelá	0.78	0.74	-
Camelias I	0.34	0.38	-
Camelias II	0.46	0.52	-
Average of First Four Fields	0.56	0.71	0.70
Average of All Fields	0.55	0.64	-

probably in large part due to the loss of raw forest litter. Apparently, a short period of second growth does not markedly change bulk density values from those found on cleared soils. A long period of forest fallow would undoubtedly restore the original soil structure found under high forest. It would be very interesting to know the bulk density values at greater depths in the soil profile in these fields but, unfortunately, an investigation along these lines was not included in the present study. It was felt that changes affecting crop growth would be reflected at depths of 5 to 10 cm. Clearly, soil compaction is not limiting crop production in this area since the bulk density values are very low, ranging from 0.20 to 0.94 g. per cc. The highest value found in the Polochic Valley (not represented in

Table 14) was from bottomland producing excellent crops of corn continuously; here the bulk density was 1.25 g. per cc. All fields under shifting cultivation had much lower values. Thus the argument that deterioration of soil structure is one of the main deleterious effects of shifting cultivation is not tenable in the Polochic Valley. It is possible that long continued cropping might result in over-compaction of the soil but this stage is not reached at present in the Polochic Valley.

Since bulk density is inversely proportional to per cent pore space, the low values provide an explanation of why many steep hillsides bordering the Polochic Valley have so little erosion. During torrential downpours most water percolates into the soil and consequently runoff is negligible, as has been observed by the writer on several occasions while working in the fields during heavy rainstorms. On steep slopes most erosion is by landslides--slippage of large soil masses when a lubricating film is formed between soil and bedrock as the zone becomes saturated with water.

Soil Biological Factors

Chemical and physical analyses of Polochic Valley soils collected during the summer of 1956 raised several questions concerning their biological nature. Accordingly, four fields were sampled in November, 1957 (including one field not examined previously) for biological analyses. The results of this more recent study are presented in the following three sections on nitrification, microorganisms, and nematodes.

Nitrification

Nitrification of the soil samples was measured by the Iowa test, since analysis of total nitrogen normally has very little value as an indication of the availability of nitrogen for crops. Results are presented in Figures 16 and 17. The nitrification rates were very high under the conditions of the experiment. Nitrate production reached a peak after a period of four weeks on all soils except Vega, where production had declined by this time. Mineralization of organic nitrogen was highest in the forest soil and least in the intensively cultivated field, though this difference is not too significant since the soils are not directly comparable. Interestingly, Vega had the lowest nitrification rate, though crop production in this field was very high. Likewise, this field, of all sites which were previously examined by chemical analyses, had the lowest content of nitrogen and organic matter.

The values of soil nitrate shown at zero time in Figure 16 are the amounts that were extracted by the initial leaching at the beginning of the experiment. As the graph shows, there is no apparent relationship between amounts of nitrate present in the soil and the nitrifying ability of the soil. Too often, quick tests to determine soil nitrogen status, work on the assumption that a relation does exist. Apparently for these four soils in the Polochic Valley, total nitrogen content (Table 4) is correlated more closely with nitrification than with content of nitrate. Figure 17 does not show the contents of nitrate leached from the soil at the initiation of

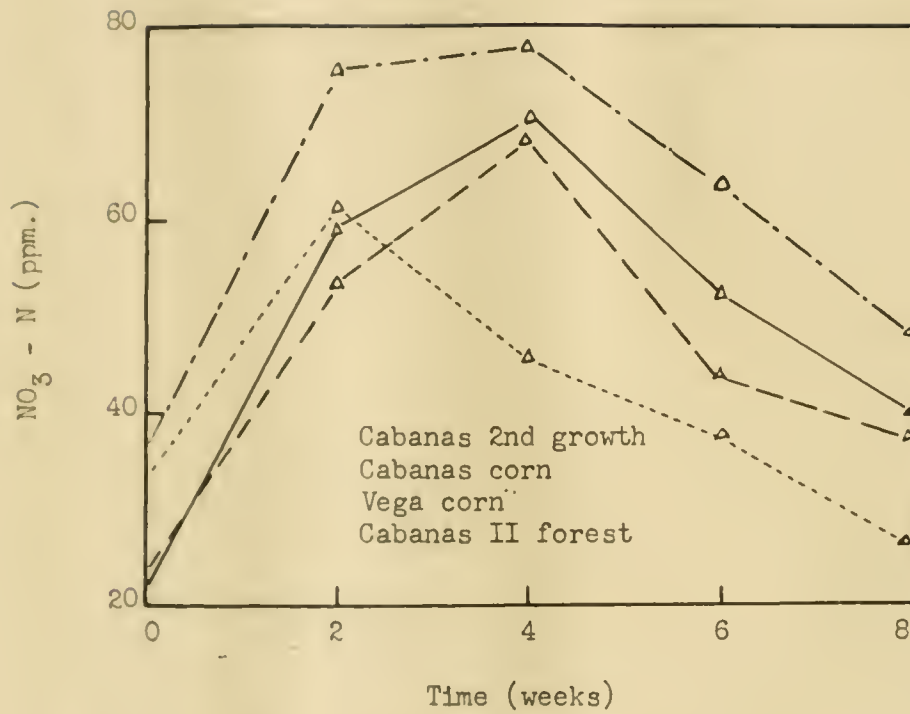


Fig. 16.--Nitrification rates of surface soils from selected Polochic Valley fields.

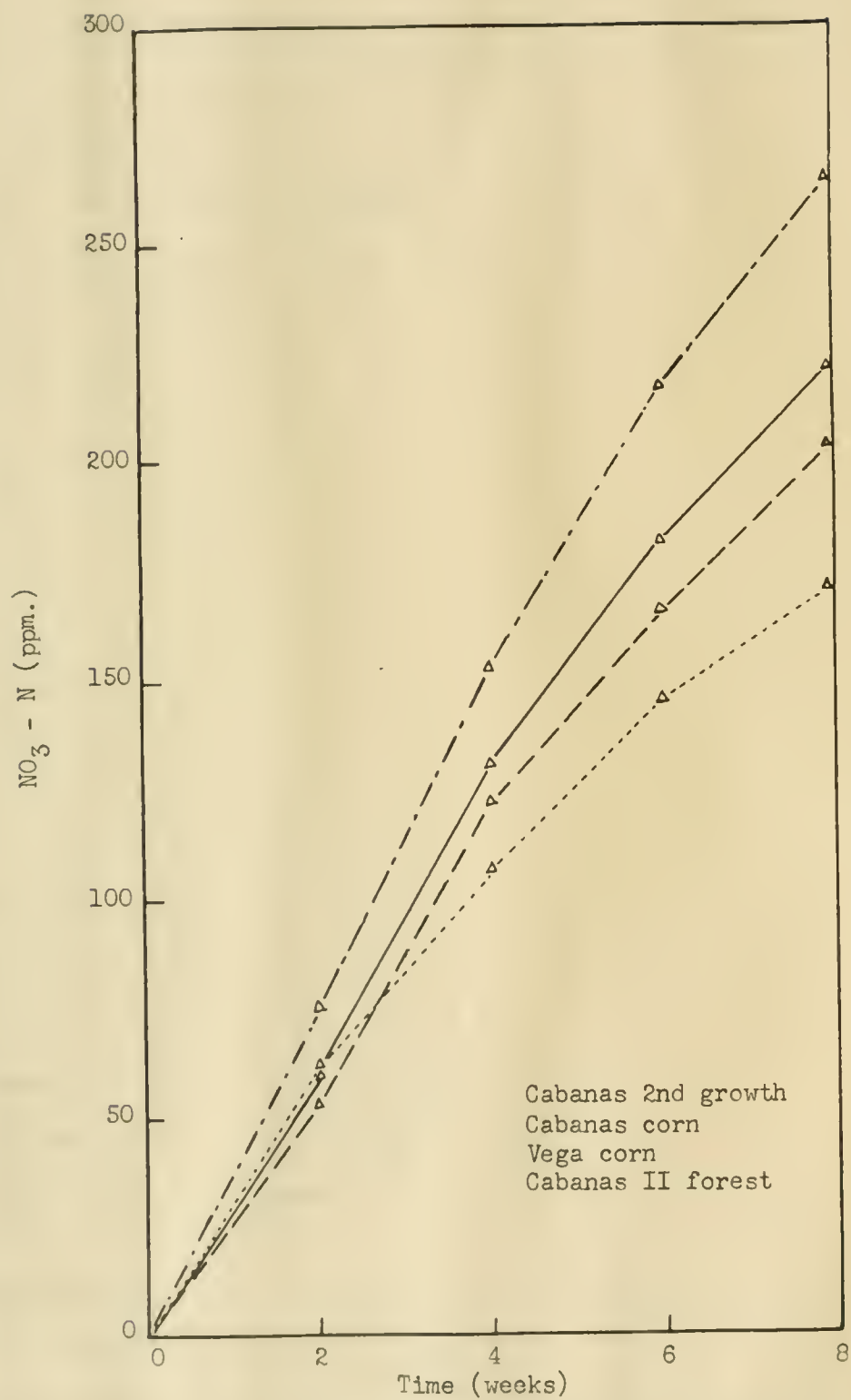


Fig. 17.--Cumulative production of nitrate nitrogen in surface soils from selected Polochic Valley fields.

nitrification studies, otherwise the initial amounts would be reflected in the cumulative production values throughout the period of investigation.

The question of adequate nitrification on very acid soils in the Polochic Valley is still unanswered since none of the soils examined had a very low pH. Furthermore, laboratory conditions do not duplicate the effects of climate in the field. Data of Greenland (1958) and Hardy (1946a) indicate that high concentrations of soil nitrates can occur at two different times, depending on the distribution of rainfall. In areas of marked dry seasons, high concentrations of nitrates are found in the soil for several weeks during the early part of the wet season and are available to crops at that time. Good growth of crops at the beginning of the summer rains and a subsequent decline in growth may be partially attributable to this mechanism. In areas of mild dry seasons, nitrates accumulate during the dry periods but are rapidly leached at the onset of heavy rains. The latter climatic pattern is characteristic of parts of the Polochic Valley. If, however, there is no dry season or it is extremely mild, as sometimes occurs in the Polochic Valley, one would expect no nitrifiable material to accumulate and nitrates to be leached almost as rapidly as they are formed.

Microorganisms

Relative numbers of fungi, streptomyces and bacteria were counted on the soil samples from the four fields. Results are given in Table 15.

TABLE 15

NUMBERS OF STREPTOMYCES, BACTERIA AND FUNGI IN SURFACE
SOILS FROM FOUR POLOCHIC VALLEY FIELDS

Field	Number of organisms per gram of soil ^a		
	Streptomyces (X 10 ⁵)	Bacteria (X 10 ⁵)	Fungi (X 10 ³)
Cabanas, 2nd growth	19	196	420
Cabanas, corn	20	96	448
Vega, corn	19	90	44
Cabanas II, forest	24	125	102
LSD	19:1	NS	38.8
	99:1	NS	54.4
			67.3
			94.3

^aMean of five plates

No unusual population characteristics are apparent. However, there are differences in populations among the various fields. Since the fields are not directly comparable, no assumptions can be made from the data about the effects of shifting cultivation on soil microflora.. Investigators in other areas have presented conflicting results of the effects of burning on soil microorganisms in the tropics; Meiklejohn (1955) reported a negative effect, and Suarez de Castro (1957) and Corbet (1935) maintained that soil populations are unaffected. Elsewhere, a positive effect of burning on soil microorganisms, particularly bacteria, was noted (Anonymous, 1950).

Nematodes

Nematodes have recently gained prominence in soil fertility investigations. Many responses to fertilizer on otherwise fertile soils may be due to the increased supply of nutrients to a root system

drastically reduced by nematode damage. The possibility arises that nematodes could be one of the limiting factors in crop production in shifting cultivation, and that the forest fallow serves merely to reduce the numbers of plant parasitic nematodes on the crop. Leap (1955) has suggested that nematodes might have caused the downfall of the Maya Empire and Thorne (1959) has stated: "It has been suggested that the Empire of the Incas in South America may have disappeared because of nematode infestation of the corn crops."

Results of plant parasitic nematode investigations on soil samples from the Polochic Valley are given in Table 16. The values of three samples in each field have been summed and presented as one value.

TABLE 16
PLANT PARASITIC NEMATODES FOUND IN FOUR
POLOCHIC VALLEY FIELDS

Nematode	Nematode numbers per 300 ml. soil			
	Cabanas 2nd growth	Cabanas corn	Vega corn	Cabanas II forest
<i>Aphlenchus avenae</i>	9	2	-	14
<i>Belonolaimus</i> sp.	1 ^a	-	-	-
<i>Criconemoides peruenae</i>	9	-	-	-
<i>Criconemoides</i> sp.	4	12	-	1
<i>Ditylenchus</i> sp.	-	-	17	-
<i>Helicotylenchus</i> spp.	507	158	134	152
<i>Hoplolaimus</i> sp.	1	-	-	-
<i>Meloidogyne</i> sp. (larvae)	22	3	-	-
<i>Paratylenchus</i> sp.	-	-	1	-
<i>Pratylenchus brachyurus</i>	1	2	1	-
<i>Pratylenchus</i> spp.	8	20	2	2
<i>Rotylenchus</i> sp.	-	-	some	-
<i>Tylenchus costatus</i>	-	12	2	-
<i>Xiphinema</i> spp.	30	-	5	67

^a Possible contamination

The results are inconclusive. The plant parasites most likely to cause damage to corn are Pratylenchus spp. and Belonolaimus sp. The method of sampling used is not the best procedure for Pratylenchus. The numbers found in the soil indicate that there is certainly some damage but more thorough sampling during the growing season for corn is needed. The finding of only one specimen of Belonolaimus indicates a possibility of laboratory contamination, perhaps of the Baermann apparatus. The presence of this species is queried pending additional samples.

Of the remaining genera the most likely candidate for corn damage based on numbers found is Helicotylenchus. (Counts here reported include the very closely related genus Rotylenchus). While this nematode has been found in large numbers in some areas of the United States, its relationship to corn decline is not known. Experiments should be conducted locally to determine the effects of this genus on corn. The specimens of Meloidogyne were larvae, and appeared to be the same as the larvae recently described as M. inornata by Loredello in Brazil. The effect of this genus on corn is not known. Xiphinema spp. are not considered damaging to annuals. They are often abundant on the roots of perennials and in established sod. Cricemoides has not yet been incriminated as a serious plant parasite. Ditylenchus spp. are often severe in oats but feed in the bud and stem, not from the soil.

One soil sample from Cabanas II forest included specimens of the interesting marine genus Desmoscolex; its presence in soil has not heretofore been reported.

Soil Fertility in the Polochic Valley

The present investigation was designed to measure changes that take place in the soil during the shifting cultivation cycle. However, as a result of the study, one might indulge in speculation on the general fertility level of soils in the Polochic Valley.

Good forest growth as an indicator of soil fertility in the tropics has always been very deceptive. Over 1900 years ago, Pliny the Elder (quoted by Ramaley, 1940) noted that forest growth was a deceiving indicator of soil fertility. He said: "A soil that is adorned by tall and graceful trees is not always a favorable one except of course for those trees." In no place is this statement more true than in the tropical rain forest environment. One of the great pitfalls in man's attempts to introduce modern agricultural technology into the humid tropics has been the tendency to overestimate the fertility of soils supporting a dense stand of virgin rain forest. Since most of the plant nutrients are tied up in the vegetation or rapidly decaying leaf litter, evaluations of inherent fertility of the soil based on appearance of the vegetation are apt to be misleading. In many places, almost identical stands of forest trees will be found on fertile and nonfertile soils lying side by side. So it is in the Polochic Valley. However, differences in soil fertility are often more obvious under second growth than under high forest.

Soil fertility laboratory data from Polochic Valley fields which were actually planted in corn during the summer of 1956 are summarized in Table 17. Although chemical analyses per se do not give

TABLE 17
CHEMICAL AND PHYSICAL ANALYSES OF SHIFTING CULTIVATION SOILS PLANTED WITH CORN
DURING THE SUMMER OF 1956 IN THE POLOCHIC VALLEY

Location	Depth cm.	pH	Ex. Cap. me./100g.	Chemical Content						Bulk	
				N	O.M.	K	Ca	Mg	P	Al	Density
				Per cent	Per cent	ppm.	ppm.	ppm.	ppm.	ppm.	g./cc.
Los Alpes	0-5	5.4	129.5	1.36	44.5	834	5725	1083	55.5	48	-
	5-20	4.3	49.7	0.49	14.4	237	952	90	2.3	147	0.42
	20-40	4.6	40.2	0.20	4.2	40	151	25	1.5	92	-
Seamay	0-5	5.1	32.0	0.37	7.3	48	761	117	3.8	60	-
	5-20	4.5	26.6	0.25	5.3	32	271	38	1.8	92	0.70
	20-40	4.4	27.0	0.17	3.6	30	96	54	1.3	101	-
Matanzas I	0-5	7.1	52.7	0.63	9.7	516	6210	966	28.8	22	-
	5-20	6.5	44.3	0.37	6.3	230	4530	891	30.5	15	0.78
	20-40	7.2	45.1	0.26	3.6	170	6240	213	3.6	20	-
Matanzas II	0-5	7.2	59.4	0.62	13.0	224	9765	1306	23.4	27	-
	5-20	6.7	47.0	0.31	7.0	116	5275	1135	5.5	19	0.94
	20-40	7.1	45.1	0.13	2.1	96	4640	1042	7.6	30	-
Actelá	0-5	5.5	32.5	0.61	12.7	272	2113	322	31.8	50	-
	5-20	4.8	28.5	0.42	10.9	78	723	106	3.1	43	0.74
	20-40	4.7	23.7	0.23	4.6	50	250	70	18.2	80	-
Camelias I	0-5	4.0	68.5	1.10	26.3	110	344	166	21.3	59	-
	5-20	4.5	39.8	0.51	13.5	42	< 100	< 25	4.3	56	0.38
	20-40	4.8	31.2	0.32	6.9	50	< 100	< 25	0.6	39	-
Camelias II	0-5	4.4	62.0	1.03	25.1	160	573	105	20.5	55	-
	5-20	4.5	41.8	0.66	14.7	44	< 100	< 25	2.8	86	0.52
	20-40	4.7	42.3	0.37	8.0	64	< 100	< 25	2.7	53	-
Vega (productive field)	0-5	5.7	22.5	0.23	4.7	224	2152	340	10.9	21	-
	5-20	5.6	20.6	0.19	3.8	124	1901	146	3.2	30	1.25
	20-40	5.2	14.8	0.08	1.4	76	897	33	3.9	28	-

an absolute estimate of soil fertility, certain possibilities are suggested. For instance, pH, potassium and phosphorus are very low in the field at Seamay, whereas aluminum is rather high. Soils of Camelias I and II have extremely low calcium, magnesium and pH values, whereas potassium is moderately low. Soil pH values at Los Alpes and Actela' are low and would likely be much lower if farmed continuously. The fields of Matanzas I and II appear to have a high fertility level; possibly a biotic or chemical factor not measured in this investigation prevents continuous crop production there. All of these fields have been cleared by burning, and because of this they are, in many respects more fertile than soils under forest or second growth. However, continued cultivation without the use of fertilizers would certainly destroy much of this burning-induced fertility through crop removal, leaching and erosion.

The Vega site is an example of productive, continuously-cropped land in a high rainfall tropical region where shifting cultivation is the dominant form of land use. Most nutrient levels of Vega soils (Table 17) are intermediate between the extremes of values for the shifting cultivation fields. Two factors are responsible for the continued productivity of Vega: (1) it is a fertile floodplain soil, and (2) the use of heavy machinery for cultivation limits weed competition. Other fields in the Polochic Valley floodplain, in which no machinery is used, are farmed much more intensively than their counterparts on the hillsides. This observation might put the onus on soil fertility (including erosion) rather than weeds as the main limiting factor in crop production in this area.

Differences in the length of shifting cultivation cycles within an area may be attributable to the soil, even though weeds also may be of major importance. A longer period of second growth might indicate that more time is needed before adequate soil conditions for crop growth are restored. Or, since vegetative regeneration is slower on less fertile soils, a longer period of forest fallow is needed for woody plants to crowd out the more herbaceous weeds. Of course, source of seed or vegetative material is also an important factor in reforestation of cleared lands.

SUMMARY AND CONCLUSIONS

Shifting cultivation is a successful agricultural system that has survived for millenia in the humid tropics. An understanding of its ecological basis, as well as cultural, is necessary before useful concepts of this system can be incorporated into other more productive systems of land management. A review of literature on soil changes that occur when forest is felled and burned, and afterwards regenerates, yields conflicting results, indicating that effects are not the same everywhere. With this in mind, an investigation of the basic soil properties and their interrelationships with shifting cultivation under a wide range of ecological variables (elevation, rainfall, geology, soils, topography) was undertaken on mountain slopes bordering the Polochic Valley in Guatemala.

The Polochic Valley is in the very humid tropics (annual precipitation of more than 100 inches) where rain forest is the climax form of vegetation. Most shifting cultivation in the area is a partial system, since the Kekchis devote only part of their time to their own fields. The remainder of the year is devoted to work on the large coffee farms in the area. Corn is the main staple, and this emphasis on a single cultigen simplifies the task of measuring the effects of shifting cultivation on the soil properties. Corn is planted in the ashes of felled and burned forest: no tillage is used. After one year of cropping, the fields are abandoned to forest

second growth. Weeds are an important factor in limiting crop production--grass rarely so.

Soils from three depths in thirty fields at eight sites, where two or more stages of shifting cultivation (forest, cleared land, second growth) adjoined were sampled to measure changes in soil properties occurring during the shifting cultivation cycle. Laboratory analyses of these samples included: clay mineral types; total content of nitrogen and organic matter; cation exchange capacity; exchangeable bases (calcium, magnesium, potassium and sodium); extractible phosphorus, aluminum, manganese and zinc; and bulk density. Subsequently, topsoils from four fields in the same area were examined for nitrification rates, microorganisms and nematodes. The findings are discussed with reference to the shifting cultivation cycle and the characterization of basic soil relationships in the Polochic Valley.

The study reveals certain anomalies in our concepts of shifting cultivation in relation to soil properties. For example, the low bulk densities, high organic matter contents, high exchange capacities, and high potassium contents have not been generally associated with areas of shifting cultivation. Dominant clay mineral types are three-layered with some inter-stratification.

Soil changes accompanying removal of forest by felling and burning are most evident in decreased nitrogen and organic matter contents and exchange capacities. However, nitrogen and organic matter are very high and the slight reduction probably does not affect plant growth. Cation exchange capacity is positively related to organic

matter, especially at higher contents, and as such is relatively sensitive to small changes in forest humus. However, since neither the high amounts of organic matter or cation exchange capacity appear to be related to exchangeable cations in these soils, changes occurring in either or both are probably of relatively little importance to plant nutrition in the Polochic Valley. Stages of shifting cultivation have little effect on base saturation, a concept which is of limited use in discussing Polochic Valley soil fertility. Revegetation of abandoned clearings by second growth restores nitrogen and organic matter lost during destruction of the original forest.

Exchangeable cations (excluding hydrogen) and pH are somewhat increased by the clearing and burning operations, but this beneficial effect is short-lived due to leaching and erosion. Bulk density values are increased when forest is removed, but all the values are exceptionally low and definitely do not limit crop production. Erosion is very slight on the steep lands of the Polochic Valley, probably due to excellent soil physical conditions. The effect of young second growth in most places has been to slightly restore original forest conditions, though phosphorus contents decline. It is possible that changes which occur during two years of forest regrowth are too small, or variability too great, to be detected by the sampling and analytical procedures used in this study.

The microbiological data revealed no unusual population characteristics. Nitrification rates were high under the conditions of the experiment. Nematode analyses were inconclusive though many plant parasitic nematodes were found and tabulated.

Soil fertility may limit continuous agricultural production of many Polochic Valley fields under shifting cultivation. Most sites (except Matanzas I) appear to have at least one plant nutrient in short supply. However, field fertilizer experiments would be necessary to verify nutrient deficiencies observed in the field and indicated by the chemical analyses of soil samples. The concentrations of exchangeable bases in Polochic Valley soils are highly variable--nutrients low in one site may be high in another. Cleared fields are generally more fertile than soils under forest, but continued crop production without fertilizers would soon deplete the temporary supply of nutrients released by burning.

This study has revealed certain fundamental relationships of Polochic Valley soils, despite the wide variability of ecological conditions:

1. Cation exchange capacity is directly related to organic matter.
2. Soil pH is directly related to exchangeable calcium and inversely related to exchangeable aluminum.
3. Exchangeable aluminum is inversely related to exchangeable calcium.
4. There is no obvious relation between either exchange capacity or organic matter and any or all of the exchangeable nutrient cations.

These relationships are quite evident and exist despite the fact that soils vary widely in pH, exchange capacity, organic matter, nutrients and clay minerals. A rough approximation of soil cation nutrient status for the Polochic Valley can be obtained from soil pH

values, but apparently not from organic matter, exchange capacity or per cent base saturation data.

Shifting cultivation appears to be a very conservative agricultural practice in the Polochic Valley, where the forests now have no great commercial value. These lands produce a limited amount of crops with no apparent permanent injury to the soils. Where fertilizers are unavailable or relatively expensive, a practice such as shifting cultivation, which requires no outlay of capital, is likely to evolve. However, shifting cultivation lands in the Polochic Valley are now saturated and further increasing population pressures will probably result in impoverishment of soil fertility and increased damage by erosion.

This study, which has surveyed many of the relationships between soils and shifting cultivation, has indicated certain beneficial, as well as detrimental, aspects of this type of land use. Basic data obtained in this investigation may be used to select the best aspects of present management practices for assimilation into more productive agricultural systems. More intensive investigations into questions raised by this work (especially soil microbiological relationships and plant response to chemical fertilizers) will provide a sounder basis for further extension of these findings.

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BIOGRAPHICAL SKETCH

Hugh Popenoe was born August 28, 1929 in Tela, Honduras. He attended grammar school in Silver Spring, Maryland, and high school in Guatemala, graduating from the latter in 1947. He enrolled in the University of California at Davis in September, 1947 and graduated in June, 1951 with a B. S. in Irrigation. He was employed during the summers of 1948 and 1950, respectively, in pineapple production in Hawaii and in soil survey work with the U. S. Bureau of Reclamation in Chico, California.

After graduation he worked for one year as Assistant Soil Scientist to Dr. R. L. Pendleton for the Economic Cooperation Administration in Bangkok, Thailand. He entered the Army in September, 1952, and after working two years as Topographic Surveyor in Alaska and California, was honorably discharged as a sergeant.

He entered the University of Florida Graduate School in June, 1954. He was employed as a Graduate Assistant, Research Associate, and now is an Interim Instructor in the Department of Soils. He received two grants from the Rockefeller Foundation and one from the National Science Foundation in support of studies on shifting cultivation and tropical land management.

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